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SOME PHYSICO-CHEMICAL RELATIONSHIPS FOUND IN FOUR EROSIVE SOILS OF THE PIEDMONT PLATEAU REGION[1]

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THE claypan nature of the B horizon of the Iredell, White Store, Helena, and Orange soils of the Piedmont Plateau Region, linked with their apparent susceptibility to severe erosion, suggested a comparative study of their profiles. The results of this study were presented in thesis form (10)[3]. An analysis of the data obtained in this investigation reveals some significant relationships existing between certain physical and chemical properties of these soils. These relationships, with some of the supporting data, are presented and discussed herein.

Certain information on the chemical composition of these soils is essential to interpret properly some of the relationships which are pointed out. Several important differences and points of similarity among this group of soils are best shown by the derived molecular values in Table 1.

Recognizing the danger of too much reliance on a total mineral analysis of soils, it seems that this method of expressing the composition data on an activity basis (molecules of the different minerals per unit weight of the soil) as suggested by Marbut (7), makes the picture less deceptive and the data more easily interpreted. The molecular equivalents show evidences of translocation of iron and aluminum compounds better than the percentage composition data, as it is usually expressed.

[1]Taken from a thesis submitted to the Faculty of Michigan State College in partial fulfillment of the requirement for the degree of master of science. Authorized by the Director for publication as Journal Article 182 n s. of the Michigan Agricultural Experiment Station, East Lansing, Mich. Received for publication September 30, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 9.

TABLE 1.—*Relative molecular equivalents and ratios of the Iredell, White Store, Helena, and Orange profiles, Halifax County, Virginia.**

Horizon	Molecular equivalent composition†			Molecular ratios		
	SiO_2	Fe_2O_3	Al_2O_3	$\frac{\text{Silica}}{\text{Alumina}}$ (sa)	$\frac{\text{Silica}}{\text{Iron}}$ (sf)	$\frac{\text{Bases}}{\text{Alumina}}$ (ba)
			Iredell Loam			
A	0.92	0.070	0.132	6.97	13.14	0.48
B	0.75	0.093	0.242	3.10	8.06	0.17
C	0.79	0.076	0.167	4.73	10.39	0.72
			White Store Fine Sandy Loam			
A_1	1.49	0.009	0.028	53.21	165.56	0.71
A_2	1.52	0.009	0.031	49.03	168.89	0.65
A_3	1.37	0.024	0.074	18.51	57.08	0.24
B_1	1.01	0.045	0.209	4.83	22.44	0.08
B_2	1.17	0.025	0.142	8.24	46.80	0.15
C	1.14	0.030	0.194	5.88	38.00	0.18
			Helena Fine Sandy Loam			
A_1	1.52	0.005	0.028	54.29	304.00	0.96
A_2	1.56	0.005	0.029	53.79	312.00	0.72
B_1	1.40	0.016	0.102	13.73	87.50	0.17
B_2	1.13	0.034	0.202	5.59	33.24	0.06
C	1.00	0.033	0.297	3.37	30.30	0.15
			Orange Silt Loam			
A_1	1.43	0.018	0.041	34.88	79.44	0.54
A_2	1.47	0.021	0.046	31.96	70.00	0.50
A_3	1.36	0.027	0.078	17.44	50.37	0.28
B	0.82	0.074	0.287	2.86	11.08	0.06
C	0.80	0.064	0.350	2.29	12.50	0.11

*These derived values were calculated from recent unpublished chemical composition data from the Virginia Agricultural Experiment Station, Blacksburg, Virginia.

†These values were obtained by dividing the percentage of each mineral by its molecular weight The molecular ratios were calculated from the molecular equivalents The bases calculated in the base-alumina (ba) ratio included CaO, K_2O, and Na_2O.

A striking similarity of the four soils is the low base-alumina (ba) figure for the B horizon, when compared with the parent material and the surface soil. Analytical data reported by Marbut (7) show the same characteristic for samples of Iredell from Iredell County, North Carolina. However, contrary to the data reported by Marbut (7), the data in Table 1 show a very definite accumulation of both iron and aluminum oxides in the B horizon of the Iredell profile. The same is true of the White Store and Orange profiles. In these soils, the molecules of these sesquioxides per unit weight of the soil are greater in number in the B than in the parent material or surface soil. The White Store, Orange, and Helena profiles show much greater losses of iron and alumina from the A horizon than the Iredell. This loss is not entirely accounted for in the concentration of these materials in the B horizon, and no doubt considerable quantities have been removed from the soil by leaching and erosion processes. The comparatively slow transition of iron and alumina in the Iredell

profile may be due to the high percentage of bases present. From the molecular relationships shown in Table 1, it is very evident that the Iredell has undergone considerable weathering and transition of materials, but not to the same degree as the other soils in this group.

METHODS AND PROCEDURE

The samples used in these studies were taken to the laboratory and screened through a 2-mm mesh sieve, air-dried, and stored. Hygroscopic moisture determinations were made by drying a 2-gram sample at 110° C for 5 hours Maximum water-holding capacity was determined by the Hilgard cup method (5) and moisture equivalent by the method of Bouyoucos (1). A mechanical analysis was made by the Bouyoucos hydrometer method (2) and the aggregate analysis by a combination of the sieve method and the hydrometer method (3).

The amount of exchangeable hydrogen and total exchange capacity were determined by the Parker barium acetate-ammonium chloride method (12). This method was modified by replacing the adsorbed ammonia with potassium by leaching the soil with 100 cc of 4% KCl. After adding NaOH to the leachate, the ammonia was distilled into sulfuric acid and determined by titration with sodium hydroxide.

SOME PHYSICAL CHARACTERISTICS STUDIED

The physical characteristics of these soils which were investigated and which have a direct bearing on the properties correlated are shown in Table 2.

The degree of aggregation of the particles in a soil has a pronounced effect on soil structure and all of its related properties. Rhoades (9) defined the state of aggregation of a soil as its ability to break up into crumbs or granules. The percentage of silt and clay which is aggregated into granules $>$0.05 mm in diameter was calculated from the dispersed and aggregate analyses data. The degree of granulation in the heavy clay zone, the least permeable zone, determines the rate of percolation of water through the profile.

PHYSICO-CHEMICAL PROPERTIES

Jenny (6) emphasized the effect of exchange adsorption on the physical, as well as chemical, properties of soils. Coagulation, dispersion, viscosity, hydration, and structure of clays are greatly affected by the nature and quantity of adsorbed ions. Differential leaching of bases is explained by the behavior of these cations during ionic exchange (13). The whole question of hydration of ions is introduced when base exchange phenomena are considered. Jenny (6) concludes that clays with adsorbed divalent cations should contain more water than those saturated with monovalent ions. The exception to this is the monovalent H ion which has long been recognized for its peculiar behavior in ionic exchange. The position in the lyotropic series, with regard to degree of hydration, of the cations involved in base exchange with soil colloids has been established. This information with a knowledge of the cation constitution of the colloids in any given soil should provide a satisfactory explanation of such physical properties as swelling and water-holding capacity.

TABLE 2.—*Textural and moisture properties.*

Horizon	Depth, inches	Dispersed analysis, %			Clay ratio*	Erosion ratio	Degree of aggregation†	Moisture content, %		
		Sand	Silt	Clay				Hygroscopic water	Maximum water capacity	Moisture equivalent
					Iredell Sandy Clay Loam					
A	0–6	57.32	18.70	23.98	3.12	43.2	47.3	1.59	49.89	23.05
B	6–18	17.82	19.55	62.63	0.58	24.0	63.4	4.83	81.02	52.02
C_1	18–22	45.54	30.95	23.51	3.25	66.7	43.9	3.04	66.85	34.74
C_2	22–26	50.34	29.75	19.91	4.02	53.5	49.7	2.58	56.09	27.75
					White Store Sandy Loam					
A_1	0–1	67.64	22.11	10.25	8.53	99.2	19.7	0.49	40.98	18.85
A_2	1–8	66.90	21.06	12.04	7.26	59.1	20.2	0.30	30.25	11.11
A_3	8–16	53.19	16.14	30.67	2.25	63.0	34.4	0.87	42.56	25.99
B_1	16–25	30.00	11.32	58.68	0.70	34.0	50.0	2.85	77.77	43.78
B_2	25–35	35.06	22.39	42.55	1.35	45.2	37.2	1.76	64.79	33.91
C_1	35–42	45.19	32.48	22.33	3.48	73.4	25.6	1.47	55.01	31.01
C_2	42–50	61.93	15.79	22.28	3.49	51.3	33.8	1.23	49.61	21.18
					Helena Sandy Loam					
A	0–6	69.85	16.52	13.63	6.29	52.1	27.0	0.17	32.29	12.96
B	6–35	27.95	11.82	60.23	0.65	80.2	12.6	2.70	80.73	60.19
C	35–42	54.79	19.48	25.73	2.89	89.7	33.6	2.43	64.38	40.54
					Orange Silt Loam					
A_1	0–8	28.73	53.63	17.64	4.60	85.3	12.2	0.24	42.64	29.68
A_2	8–16	21.49	47.18	31.33	2.18	52.0	23.6	0.41	45.72	28.77
B	16–27	10.32	15.32	74.36	0.35	27.0	56.1	2.10	91.80	46.52
C	27–38	42.23	37.50	20.27	3.93	49.7	57.8	1.33	46.68	32.15

*$\frac{\text{Sand and Silt}}{\text{Clay}}$.

†Percentage of the silt and clay in aggregates >0.05 mm.

The Iredell surface soil and parent material was neutral to slightly alkaline in reaction, whereas the B horizon was slightly acid (Table 3). The acid sandstone (parent material) influence in the White Store profile is reflected in pH and cation exchange values. White Store B_1 is only 33% saturated with bases, whereas the B horizons of Iredell, Helena, and Orange are 88%, 77%, and 85% saturated, respectively.

TABLE 3.—*Base exchange properties, pH, and organic matter content*

Horizon	Colloids, %	Organic matter, %	Base exchange: Exchangeable hydrogen, M. E.	Base exchange: Cation exchange capacity, M. E.	Base exchange: Exchangeable bases, M. E.	Base exchange: Degree of base saturation, %	pH
			Iredell Sandy Clay Loam				
A	28.05	1.32	2.69	8.03	5.34	66.5	7.3
B	68.52	0.98	3.60	30.74	27.14	88.29	6.5
C_1	29.29	----	1.78	21.21	19.43	91.61	7.2
C_2	26.07	----	1.16	17.03	15.87	93.19	7.3
			White Store Sandy Loam				
A_1	15.28	2.36	2.39	3.75	1.36	36.29	5.4
A_2	15.05	0.59	1.63	2.11	0.48	22.75	5.0
A_3	31.28	0.39	5.30	6.73	1.43	21.25	4.6
B_1	63.83	0.35	17.1	25.60	8.5	33.2	4.7
B_2	47.23	----	11.47	19.06	7.59	39.82	4.9
C_1	29.44	----	7.75	15.77	8.02	50.92	5.1
C_2	27.34	----	5.93	13.1	7.17	54.73	4.8
			Helena Sandy Loam				
A	18.13	0.65	0.89	1.73	0.84	48.55	5.5
B	65.36	0.34	4.53	19.78	15.25	77.1	5.0
C	29.83	----	1.44	14.60	13.16	90.14	6.8
			Orange Silt Loam				
A_1	30.67	1.24	2.17	2.78	0.61	21.94	4.9
A_2	42.37	0.49	2.86	5.00	2.14	42.8	4.8
B	76.00	0.56	3.21	22.31	1.91	85.6	5.3
C	27.37	----	2.19	8.46	6.27	74.11	5.6

The highly impermeable B horizon of the Helena has apparently caused a minimum loss of bases from the parent material, as shown by a base saturation of 90.14% and pH of 6.8. Chemical composition data show that this high pH was accompanied by a high K_2O content. The colloids in the Orange profile are relatively inactive, as shown by a low ratio of cation exchange capacity to colloids.

CORRELATION OF PROPERTIES

Some relationships existing in the data are best shown by correlating certain factors. The degree of association is shown by the correlation coefficients in Table 4.

TABLE 4.—*The relation between certain physical and chemical properties.*

Factors correlated	Correlation coefficient	Number of cases
Hygroscopic water and cation exchange capacity....	.923* ±.0358†	18
Percentage colloid and cation exchange capacity....	.752 ±.1053	18
H-ion concentration and percentage base saturation.	—.712 ±.1196	18
Hygroscopic water and maximum water-holding capacity....	.806 ±.0848	18
Hygroscopic water and moisture equivalent.......	.749 ±.1065	18

*Corrected for small number of cases by the formula $r^2 = 1 - (1-r^2)\frac{(N-1)}{N-2}$.

†Standard error

RELATION OF HYGROSCOPIC WATER TO CATION EXCHANGE CAPACITY

The correlation coefficient of .923 ± .0358 between hygroscopic water and cation exchange capacity is highly significant. Investigators have frequently noted the relationship between colloidal content of a soil and its ability to adsorb ions. To the writer's knowledge, no attempt has been made to correlate cation exchange capacity with another definite property of the colloidal fraction, such as its ability to hold hygroscopic water. Does the ability of a soil colloid to hold water against the evaporating forces which prevail in air-drying conditions measure its ability or properties of ionic exchange? This relationship is best illustrated in Fig. 1, showing the scatter of the data. The 18 samples used in this study represent a wide range of textural properties, types of colloids, degree of base saturation, and other properties which might influence or reflect the factors of cation exchange capacity and content of hygroscopic water. If it is assumed that water adsorption and retention is a function of, and is proportional to, the surface exposed by soil colloids, we must conclude that base exchange is primarily a surface phenomenon from its close relationship to the moisture-retaining capacity of a soil. These two properties are more closely related than percentage colloid and cation exchange capacity (correlation coefficient value of .752 ± .1053).

RELATION OF H-ION CONCENTRATION TO PERCENTAGE BASE SATURATION

A significant negative correlation was found to exist between H-ion concentration and percentage base saturation, as shown by a coefficient value of —.712 ± .1196. Walker, Firkins, and Brown (12) state, "It is reasonable to assume that the amount of replaceable hydrogen would have a direct relation to the hydrogen ion concentration of the soil". This relationship does not exist in a variety of soils with different exchange capacities. The H-ion concentration has no reference to the total amount of H ions in the soil; but, as expressed by pH, is merely an expression of an equilibrium existing between H ions and OH ions. On the other hand, a reasonably high negative correlation coefficient would be expected when H-ion concentration is correlated with the percentage base saturation. Similarly a good positive correlation would be expected between H-ion concen-

tration and the percentage hydrogen saturation, but not with total exchangeable hydrogen.

It is readily seen that a sandy soil with a given pH ordinarily contains less total exchangeable hydrogen than a heavy clay with the same pH, or a higher pH. This is excellently illustrated in the base exchange data in Table 3. Helena A (18% colloids) with a pH of 5 5 contained only 0 80 M E. of exchangeable hydrogen, whereas

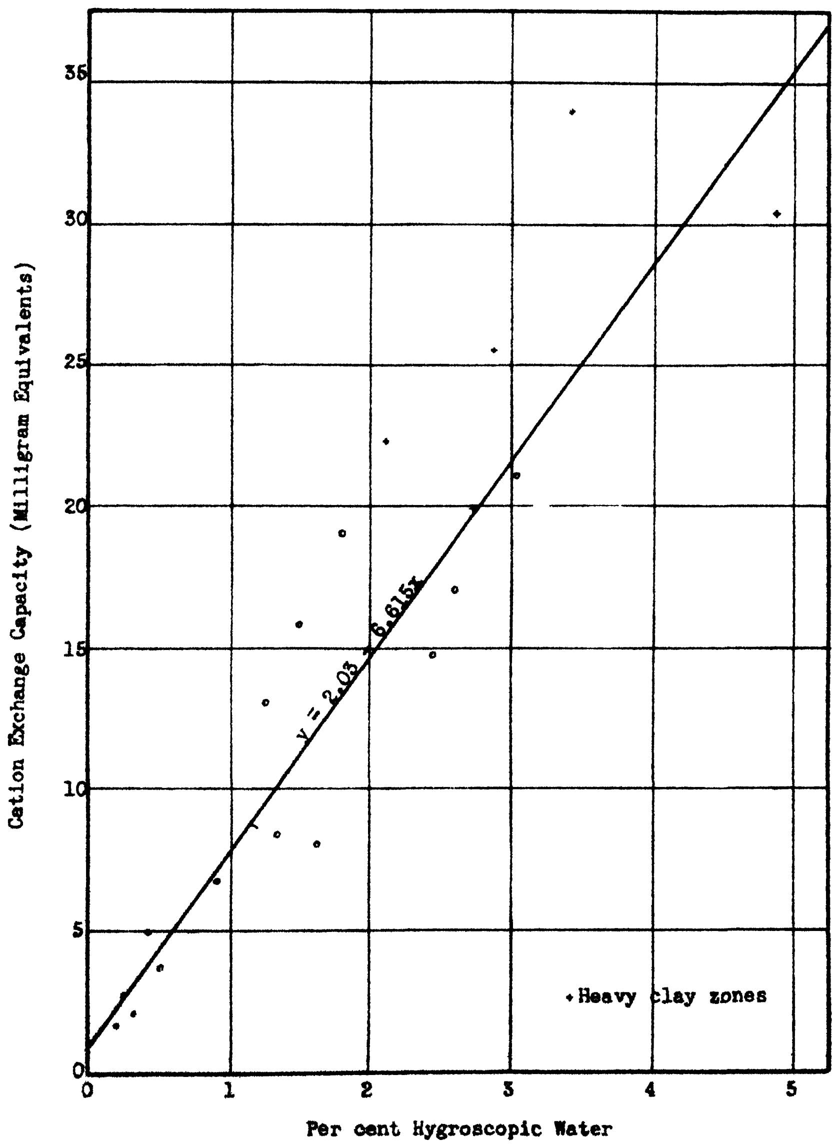

FIG. 1.—Relation of hygroscopic moisture to cation exchange capacity.

Iredell B (68% colloids) with a pH of 6.5 showed 3.6 M. E. of exchangeable hydrogen. That a close relationship does not exist between H-ion concentration and total exchangeable hydrogen is very evident from the data in Table 3, which are included in this discussion to support these conclusions. White Store B_1 with a pH of 4.7 held 17.1 M. E. of exchangeable hydrogen, whereas Orange A_2 with a pH of 4.8 held only 2.86 M. E. of this cation. Moreover, Iredell A (pH 7.3) has 2.69 M. E. of exchangeable hydrogen, which is more than found in Orange A_1 with a pH of 4.9.

A good negative correlation between H-ion concentration and percentage base saturation is illustrated by White Store A_3 with the lowest pH (4.6) of the 18 samples and the lowest percentage base saturation (21.25). Likewise, Iredell C_2 with the highest pH (7.3) has the highest percentage base saturation (93.19).

This same principle is recognized in liming sandy and clay soils. It is common observation that much greater quantities of liming materials are required to produce the same change in pH in clays than in the light-textured soils. It seems highly important that these relationships be kept clearly in mind in soil fertility studies.

The explanation lies in the fact that we are considering equilibrium conditions and not absolute quantities of the opposing forces.

RELATION OF HYGROSCOPIC WATER TO MAXIMUM WATER HOLDING CAPACITY AND TO MOISTURE EQUIVALENT

Turk and Millar (11) report a high correlation between hygroscopic water, maximum water-holding capacity, and moisture equivalent in a Hillsdale sandy loam. They concluded that, since the methods used for these determinations are arbitrary and only relative at the best, the three determinations yield results of about equal value. The high correlation coefficients obtained when hygroscopic water and maximum water-holding capacity and hygroscopic water and moisture equivalent were correlated point to the same conclusion. In view of the fact that these close relationships exist between these moisture properties in four complete profiles, their significance is emphasized as well or better than in the data reported by Turk and Millar (11), which were obtained from one soil with different treatments.

SUMMARY

1. A study of the profiles of the Iredell, White Store, Helena, and Orange soils was made. These are four highly erosive claypan soils of the Piedmont Plateau Region of the Eastern United States. An analysis of the data obtained in this study reveals some significant relationships between certain physical and chemical properties.

2. A correlation coefficient of .923 ± .0358 was found when hygroscopic water content was correlated with cation exchange capacity. These two properties are more closely related than percentage colloid and cation exchange capacity (correlation coefficient .752 ± .1053). This indicates that the ability of soil colloids to hold water against evaporation forces is an accurate measure of their ability to adsorb cations in ionic exchange.

3. A high negative correlation (−.712 ± .1196) existed between H-ion concentration and percentage base saturation. The data obtained show that there is very little relationship between H-ion concentration and total exchangeable hydrogen in soils with widely different cation exchange capacities.

4. High correlation coefficients obtained for both hygroscopic water and maximum water-holding capacity and hygroscopic water and moisture equivalent show that any one of these values may be calculated from either of the others by means of a constant, with a high degree of accuracy.

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THE INFLUENCE OF PHOSPHATE FERTILIZATION UPON THE AMPHOTERIC PROPERTIES OF COASTAL PLAIN SOILS[1]

JACKSON B. HESTER[2]

MANY of the soils in eastern Virginia have been farmed since 1700 and trucked since 1844. In the production of vegetable crops large quantities of fertilizer are used. The influence that such a long period of intensive farming would have upon the soil is likely to be significant (2).[3]

Perhaps the fertilizer constituent that is most likely to accumulate in the soil is the phosphate ion, because it does not leach and only a relatively small proportion of the added phosphate is removed by the crop. Often 1 to 3 tons of a rather concentrated fertilizer mixture is used annually per acre in the growing of several vegetable crops. For example, the figures in Table 1 show that a number of vegetable crop producing soils in the Norfolk section analyze more than seven times higher in phosphorus than their adjoining virgin soils. This is readily understood when it is realized that in the production of potatoes 52 pounds of phosphorus are used in the average fertilizer program, whereas not over 7 pounds are removed from the soil. Much of the remaining phosphorus becomes fixed by the soil colloidal complex before the next crop has been planted. The phosphate ion is so completely fixed by the surface soil that the A_2 horizon is enriched to a much less extent and the B horizon to only a moderate extent. Considering the three horizons of soil, soils around Norfolk have an enormous capacity for fixing phosphorus.

TABLE 1.—*The influence of heavy fertilization upon the phosphorus content of trucking soils.*

Horizon	Approximate inches	Parts P_2O_5 per 2 million of soil			Number of samples
		Average	Lowest	Highest	
		Trucking Soil			
A_1	0–7	4,484	3,362	6,640	18
A_2	7–14	1,714	1,458	2,916	11
B	14–21	772	742	896	6
		Virgin Soil			
A_1	2–7	590	368	940	6
A_2	7–14	396	200	708	6
B	14–20	534	200	740	4

The data in Table 2 show the influence of 12 years of known fertilization where the soil already carried a goodly supply of total

[1]Contribution from the Virginia Truck Experiment Station, Norfolk, Va. Received for publication October 5, 1936.

[2]Soil Technologist. For assistance in chemical analyses, credit is given to J. M. Blume and F. A. Shelton of this laboratory.

[3]Figures in parenthesis refer to "Literature Cited", p. 15.

phosphorus. The total absorbing power for phosphorus was obtained by shaking 10 grams of soil with a soluble phosphate in a mechanical shaker for several hours. The soluble salts were removed by leaching with water and the total analysis for phosphorus made on the dry soil. The results indicate that the surface soil where the 15% application of P_2O_5 had been made had about reached its saturation capacity. The results also indicate that very little of the phosphorus had moved below the top 6-inch soil horizon (5, 13).

TABLE 2.—*The influence of a 12-year fertilizer treatment upon the phosphorus content of a Sassafras sandy loam.*

Fertilizer used*	Parts P_2O_5 per 2 million of soil			
	Added	Found	Difference	Saturation capacity†
9-3-9	372	3,420	——	4,900
6-6-5	744	3,540	120	4,900
6-9-6	1,016	4,200	780	4,920
3-15-3	1,860	4,800	1,380	5,100

*Applied at the rate of 1,000 pounds per acre annually.
†Soil allowed to absorb all the phosphorus it would take up from solution.

When ions like the phosphate ion react with the soil colloidal complex they form very slightly dissociated combinations (3, 7, 8, 9, 10) and change the behavior and character of the soil complex. These strongly associated ions become a part of the soil complex and increase its acidic residue (9, 10). The base exchange capacity of the soil is increased and the pH at which aluminum comes into solution is lowered. Thus, it is shown in Table 3 that the exchange capacity of the soil under treatment was increased by the heavy application of phosphorus This is in keeping with the finding of Mattson (9) under laboratory conditions. Further, the soils that absorbed phosphorus from solution showed a great increase in exchange capacity. While all of the soils had about the same amount of total phosphorus after the laboratory treatment, the ones that had absorbed the largest quantity of phosphorus in the laboratory showed the greatest increase in exchange capacity. This substantiates the results of Pugh (11) in that complexes as they age decrease in exchange capacity.

TABLE 3.—*The influence of absorbed phosphorus upon the exchange capacity of a Sassafras sandy loam per 1,000 grams of soil.*

Fertilizer treatment	Exchange capacity, M. E.	Milligrams P_2O_5 absorbed from solution	Exchange capacity after P_2O_5 treatment, M. E.
9-3-9	47	760	86
6-6-5	53	680	76
6-9-6	55	360	70
3-15-3	59	150	66

PHOSPHATE-ABSORBING POWER OF THE SOILS

In order to study the phosphate-absorbing power of two principal soil types found in the vegetable producing area around Norfolk, the clay fraction of the Bladen and Norfolk series was isolated and electrodialyzed free of exchangeable bases. Each clay was then treated with a soluble phosphate at its ultimate pH state[4] and at pH 6.5 (CaO saturated) (6). Ammonium phosphate and phosphoric acid were mixed to give a pH value equal to that of the soil. The ultimate pH values of the soils were as follows: Bladen 3.6 and Norfolk 4.7. The clays extracted were from virgin soil.

The phosphate-absorbing power of the clays was in keeping with their amphoteric properties (Table 4). The calcium content at pH 6.5 no doubt influenced the absorbing power. This is brought out in the availability studies discussed later. The total quantity of CaO and the acidity of the colloid influence the amount of phosphorus absorbed by the complex.

TABLE 4.—*The absorption of phosphorus from solution by soil colloids.*

Treatment	Milligrams of P_2O_5 per gram colloid	
	Bladen	Norfolk
E colloid	1.42	4.39
Saturated with P_2O_5 at ultimate pH	7.01	16.87
Saturated with P_2O_5 at pH 6.5	7.25	21.11

AVAILABILITY OF PHOSPHORUS

In studying the availability of phosphorus, the three clays with wide amphoteric points were placed in sand cultures in the greenhouse and planted with garden peas. The experiment was conducted in 2-gallon "coffee urn lining" pots with washed beach sand. The phosphates were added on an equal weight basis of phosphorus or 100 milligrams of P_2O_5 per pot. This was a very low quantity, but sufficient to give a very good stimulation to plant growth. Commercial KNO_3, $Ca(NO_3)_2$, $MgSO_4$, NaCl, and Mn and Fe humate were added as plant nutrients. Nine garden pea seed were planted in the pot and later thinned to five. Owing to a shortage of rain water, tap water (deep well water) had to be supplemented at times as a source of water.

The relative availability (Table 5) is in keeping with the amphoteric properties of the soil. The Bladen clay has the greatest residual acidoid strength and thus shows the greatest percentage availability of the phosphorus absorbed by the colloid.

CLAY COMPOSITION AND PHOSPHATE SOLUBILITY

Again, in Table 6, is given the solubility of phosphorus from the different colloids. A similar relation exists between the ultimate pH

[4]pH of electrodialyzed soil. The acidity is governed by the amphoteric properties of the soil. An electrodialyzed soil with a wide acidoid/basoid ratio has a low ultimate pH and one with a narrow ratio a high pH.

TABLE 5. —*The influence of the composition of the soil colloid upon the availability of phosphorus.*

Soil colloid	Ultimate pH	Relative availability of phosphorus*		
		E colloid†	E colloid saturated with phosphorus	E colloid saturated with CaO to pH 6.5 and phosphorus
Bladen .	3.6	20	50	100§
Norfolk	4.7	10	45	58
Nipe‡ . .	6.0	0	38	60

*Peas grown in greenhouse in sand cultures. Phosphorus applied on an equal basis.
†Electrodialyzed free of bases.
‡A lateritic soil from Cuba introduced because of its narrow silica/sesquioxide ratio (0.31). Described by Mattson.
§17.02 milligrams of phosphorus absorbed above that present in the plants on the check pots.

and the solubility of phosphorus as was shown for plant absorption. The influence the calcium ion exerts in the solubility of phosphorus is brought out as compared to the electrodialyzed clay.

TABLE 6. —*The influence of the composition of the soil colloid upon the solubility of phosphorus.*

Soil colloid	Ultimate pH	P p.m.* in solution in H_2O†		
		E colloid‡	E colloid saturated with phosphorus	Saturated with CaO to pH 6.5 and phosphorus
Bladen . .	3.6	0.18	26.3	61.8
Norfolk	4.7	0.10	17.0	24.0
Nipe	6.0	0.04	4.1	10.3

*Also percentage of total phosphorus in colloid in solution.
†Dialyzed in colloidon bags 72 hours. Samples equivalent to 10 mg P_2O_5 in 100 mls H_2O.
‡Electrodialyzed.

PHOSPHATE FIXING POWER OF THE NORFOLK SOIL.

A virgin Norfolk very fine sand was brought to the greenhouse and screened and placed in 2-gallon "coffee urn lining" pots. The P_2O_5 content of the soil was increased from 316 to 1,740 parts per million in the native soil and from 350 to 1,076 in the soil to which peat moss had been added as a source of organic matter. The phosphorus was thoroughly incorporated with the soil and four successive vegetable crops were planted in the soil. Abundant nitrogen, potassium, and minor elements (Cu, Mn, Zn, B) were given each crop. The response to the highest application of phosphorus in the low organic matter series was pronounced, but not a very great response above the first application of phosphorus in the organic matter series was noted. The organic matter greatly influenced the rate at which the soil fixed the phosphorus. Plants practically stopped growing after the fourth crop from a lack of available phosphorus in the high phosphate treated soil without organic matter, whereas several other fair crops could have apparently been grown where the

organic matter was added. In fact, no depressed yield was noted after the fourth crop.

The data in Table 7 bring out the fact that, from the standpoint of the availability of added phosphorus, this Norfolk soil was very inefficient. Organic matter increased its efficiency.

TABLE 7.—*Influence of soil treatment on the availability of phosphorus in a Norfolk very fine sand per 1,000 grams of soil.*

Milligrams P_2O_5 in soil*	Grams of plant material dry weight†	Milligrams P_2O_5 absorbed	Per cent of total P_2O_5 absorbed	Per cent of applied P_2O_5 absorbed
1 Per Cent Organic Matter, 5 Per Cent Clay, pH 6.2				
316	0.9	2.3	0.7	
488	6.6	40.5	8.3	23.5
630	9.3	71.9	11.4	22.9
1,029	13.1	117.9	11.5	16.5
1,740	16.5	178.9	10.3	12.5
3 Per Cent Organic Matter, 5 Per cent Clay, pH 6.2				
350	7.3	29.8	8.5	
537	12.3	68.2	12.7	36.5
711	15.1	104.7	14.7	29.0
1,076	17.4	169.9	15.8	23.4

*Built up with superphosphate.
†Kale, collards, peas, and lima beans.

MECHANISM OF PHOSPHATE FIXATION

The work of Mattson (9, 10) and others (7, 8, 11) has shown that the soil colloid is composed of an acidoid/basoid complex. The greater the acidic residue, the greater the exchange capacity of the clay. Phosphorus (10) combines with the basoid complex to reduce its strength and increase the acidoid strength. For example, in Table 8 the soil with the strongest acid residue, Bladen, absorbed the least amount of phosphorus, while the Norfolk absorbed the greatest amount of phosphorus and resulted in the greatest increase in exchange capacity. The absorption of phosphorus for the Bladen clay was 5.59 milligrams of P_2O_5 per gram of colloid and a 41% increase in exchange capacity.

TABLE 8.—*The influence of the absorbed phosphorus upon the exchange capacity.*

Treatment	Milliequivalents per gram of colloid					
	Bladen			Norfolk		
	Mg P_2O_5 absorbed	Exchange capacity	Per cent increase	Mg P_2O_5 absorbed	Exchange capacity	Per cent increase
E colloid	—	0.395	—	—	0.290	—
Saturated with P_2O_5 at ultimate pH	5.59	0.555	41	12.48	0.515	78
Saturated with P_2O_5 at pH 6.5	5.83	0.605	53	16.72	0.580	100

The clays took up more phosphorus at pH 6.5 than at the ultimate pH; likewise, the exchange capacity was increased somewhat more in proportion to the amount absorbed After determining the exchange capacity of the clays, they were leached with 0.02 normal aluminum chloride until aluminum absorption ceased and again the exchange capacity was determined by leaching with neutral calcium acetate and replacing the calcium with ammonium chloride. The decrease in exchange capacity due to this treatment is shown in Table 9. The clays were again leached with 0 1 normal sodium ammonium phosphate and the absorbed phosphorus determined after washing out the excess salts with a water-alcohol mixture. These data are given in Table 10. It is shown here that if the basic

TABLE 9 —*The influence of $AlCl_3$ upon decreasing the exchange capacity.*

Treatment	Milliequivalents per gram of colloid			
	Bladen		Norfolk	
	Exchange capacity	Per cent decrease	Exchange capacity	Per cent decrease
E colloid	0.195	51	0.115	60
Saturated with P_2O_5 at ultimate pH	0 190	60	0.145	72
Saturated with P_2O_5 at pH 6 5	0.220	64	0.170	71

TABLE 10.—*The influence of $AlCl_3$ upon phosphorus absorption.*

Treatment	Milligrams of P_2O_5 absorbed	
	Bladen	Norfolk
E colloid	15 94	25.41
Saturated with P_2O_5 at ultimate pH	20.79	20.71
Saturated with P_2O_5 at pH 6.5	18.09	14.11

residue of the soil be increased by aluminum, the phosphate-absorbing power becomes much greater. From this it is indicated, as has been shown before (1, 4, 9, 10, 11, 12), that the seat of the phosphate-absorbing power of the soil is in the basoid constituent of the soil colloid.

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POTASSIUM RETAINED IN THE EXCHANGEABLE FORM BY SOME MARYLAND SOILS[1]

R. P. THOMAS and J. E. SCHUELER, JR.[2]

IT is generally considered that an application of potassium to the soil normally will remain in more or less of an available form until it is used either by the crop or lost by leaching. This assumption is based largely on the high percentage of recovery by base exchange methods of the potash applied. A knowledge of the amount of exchangeable potassium found in a soil should then indicate the need and the efficiency of potash fertilization. Such determinations were made on several orchard soils in Maryland. The data obtained in this study are briefly presented.

Soil samples from several commercial orchards in the state on which the Horticultural Department were conducting fertilizer tests were used for this purpose. Different kinds and amounts of fertilizer treatments were made annually for the past 4 years. The treatment of the soils used in this study and the total amount of potassium applied is given in Table 1. All fertilizers were applied by hand to the surface soil under the limb spread of the trees. Any cultivation to work in the fertilizer was by necessity shallow with the result that most of the fertilizer movement in the soil had to be by percolation. These orchards were located in different parts of the state and represented the Sassafras, Manor, Penn, Berks, and Hagerstown soil series The texture of these soils varied from a sand to a clay loam. Even in the individual orchards there was considerable variation; however the class given in Table 1 represents the predominating one for each orchard The samples of soil were secured from under the trees by the use of a post hole digger. This method of sampling was necessary in some of the soils because of the large amount of rock and gravel. These samples were air dried and screened through a 10-mesh screen and all the rock and gravel discarded.

The exchangeable potassium was determined by a modification of the Schollenberger-Dreibelbeis method[3]. Briefly this procedure was carried out in the following manner: Duplicate 100 grams of each soil were leached with 750 ml of normal ammonium acetate which had been adjusted to pH 7.07. The leachate was mixed and divided into thirds. Each portion was evaporated to dryness in a 250 ml beaker. The ammonium acetate residue was treated with aqua regia to destroy the organic matter. This generally required two treatments of about 10 ml each to drive off all the organic residues. The dry beaker was flamed in order to remove all the traces of ammonia. It was necessary to do this carefully in order to prevent loss of potassium by volatilization, not to break the beaker, and to obtain

[1]Contribution from the Agronomy Department, University of Maryland, College Park, Md. Published with the consent of the Director of the Agricultural Experiment Station. Received for publication October 9, 1936.

[2]Associate Professor and Graduate Assistant, respectively.

[3]SCHOLLENBERGER, C. J., and DREIBELBIS, F. R. Analytical methods in base exchange investigations on soils. Soil Science, 30:161–173. 1930.

TABLE 1.—*The influence of fertilizer treatments on the pounds per acre of exchangeable potassium in the first 18 inches of soil by 6-inch depths.*

Fertilizer treatment	Potassium added in fertilizer, lbs.	Lbs. of exchangeable potassium found by 6-in. depths		
		0–6 in.	6–12 in.	12–18 in.
		Sassafras Sandy Loam		
N, KCl......	460	581	409	102
N	—	120	49	49
N, KCl.....	230	617	200	77
N, K_2SO_4....	230	481	214	62
		Sassafras Fine Sandy Loam		
N, KCl	352	232	323	243
N, K_2SO_4....	352	253	262	225
N	—	204	97	84
N, KCl.....	704	528	512	361
		Sassafras Loamy Sand		
N, KCl....	352	115	146	127
N, K_2SO_4....	352	120	116	84
N, KCl	704	117	151	128
N .	—	57	62	63
		Sassafras Sand		
N, KCl .	230	205	211	227
Lime, N, KCl	230	318	219	170
N......	—	90	85	72
N, KCl . .	460	210	157	143
		Manor Loam		
N, K_2SO_4 ..	352	782	136	99
N, KCl . .	352	845	181	103
N . .	—	143	57	63
N, P .	—	141	57	55
N, P, KCl . .	970	933	138	68
KCl . . .	970	674	106	71
		Penn Gravelly Loam		
N, KCl...	460	1,058	323	99
Lime, N, KCl	230	636	126	99
K_2SO_4 . ..	460	834	209	92
N..	—	99	49	65
		Berks Silt Loam		
N, KCl...	704	421	192	90
N..	—	181	93	93
N, P, KCl....	352	861	545	152
Lime, KCl	352	586	316	103
P...	—	194	75	87
		Hagerstown Clay Loam		
N, P. . . .	—	305	167	148
Lime, N, KCl	230	462	186	124
N...... ..	—	373	258	304
N, KCl... ..	460	1,769	678	405

a complete removal of the ammonium salts. The salt residue was then taken up with 10 ml of water and 1 drop of concentrated hydrochloric acid. The use of a rubber policeman aided considerably in

bringing all of the salts except silica into solution. The volume was then made up to 25 ml and neutralized with N/10 sodium hydroxide, using phenolphthalein as an indicator. Two drops of acetic acid and 10 ml of alcohol were added. After the solution had been cooled at 6° C, the potassium was precipitated by sodium cobalti nitrite and determined by the method of Schueler and Thomas,[4] The method was occasionally checked by the modified J. Laurence Smith platinic chloride procedure.

The results obtained by this method are given in Table 1. Since the samples were taken by 6-inch depths, the potassium is recorded in terms of pounds per acre for each depth. Since all three of the layers were of the same thickness it was assumed that each was equivalent to 2,000,000 pounds per acre. Each value for exchangeable potassium represents an average of four separate determinations in duplicate for each treatment listed except the Manor loam. For this soil each value is an average of five determinations in duplicate. It is noted that some of the values are abnormally high. This is believed to be due to some undecomposed potash fertilizer obtained in the sampling. The total amount of potassium that was applied during the previous 4 years is shown in the table. For convenience the data will be explained by soil series.

In the Sassafras soils the application of potassium increased considerably the exchangeable amount of this element in the first 6 inches of soil. However, this increase was not proportional to the rate of application. The fertilization resulted in an additional amount in the second and third 6-inch layer, although the third layer did not contain as much potassium as the second layer The data show that the coarser the soil texture, the smaller the amount of exchangeable potassium. There is also an indication that in these soils the potassium content can not be increased above a certain level. This is probably because of the low exchange capacity of the soil. The data given for these soils in Table 2 show a low total exchange capacity and a small percentage of potassium in the exchange complex. From these results it would seem that a heavy application of potash fertilizer at one time on these soils would not be economical. In all probability it would be better to make more frequent applications of smaller quantity. Such soils should respond to a side dressing of potash fertilizers if the crop is one which requires considerable potassium.

In the Manor loam soil most of the potassium was retained in the exchange complex of the first 6-inch layer. Since the 300-pound application showed almost as much exchangeable potassium as the 900-pound treatment, it would seem as if the sorption complex has a limited capacity for this element. The data in Table 2 show this capacity to be much less than one-half of the exchange capacity. The movement into the second 6-inch layer was small while still less was retained in the third 6-inch layer. Manor is an immature soil derived from micaceous schists and gneiss. It is frequently described as having an A-C profile. For that reason it should not be high in available or retain much potassium in the 6- to 18 inch layer.

[4]SCHUELER, J. R., and THOMAS, R. P. Determination of potassium by sodium cobaltinitrite. Ind. and Eng. Chem., Anal. Ed., 5:163–165. 1933.

TABLE 2.—*The total exchange capacity and the influence of potassium fertilization on the exchangeable potassium in some Maryland soils.*

Potassium added in fertilizer, lbs. per acre	Total exchange capacity, M. E.	Potassium in exchange complex	
		M. E.	%
	Sassafras Sandy Loam		
0	1.90	0.15	7.9
230	1.90	0.79	41.6
460	1.90	0.74	38.9
	Sassafras Fine Sandy Loam		
0	2.00	0.26	13.0
352	2.00	0.30	15.0
704	2.00	0.68	34.0
	Sassafras Loamy Sand		
0	1.80	0.07	3.9
352	1.80	0.15	8.3
704	1.80	0.15	8.3
	Sassafras Sand		
0	1.55	0.12	7.7
230	1.55	0.26	16.8
460	1.55	0.27	17.4
	Manor Loam		
0	3.75	0.18	4.8
352	3.75	1.08	28.8
970	3.75	1.19	31.7
	Penn Gravelly Loam		
0	3.60	0.13	3.6
230	3.60	0.81	22.5
460	3.60	1.35	37.5
	Berks Silt Loam		
0	3.85	0.23	6.0
352	3.85	0.75	19.5
704	3.85	0.54	14.0
	Hagerstown Clay Loam		
0	8.55	0.48	5.6
230	8.55	0.59	6.9
460	8.55	2.26	26.4

The texture and sorption complex are both suitable for a high retention in the surface layer and unsuitable in lower layers. From the results for this soil it would hardly seem justifiable to make a very large application of potash. The rugged topography of the surface and the lack of a B horizon are not favorable for such a practice.

The Penn gravelly loam soil was quite similar to the Manor soil in its retention of available potassium. The unfertilized soil was much lower in its available potash, but the soil seemed to have practically the same retentive capacity. The second 6-inch layer of Penn soil was able to retain considerable potash; and either very little reached the third layer, or it did not remain there. The Penn soils have usually

a better developed B horizon than Manor. This should permit a higher absorption of potash in the 6- to 18-inch layer as the data in Table 1 indicate. From these observations it should be possible to increase the available potassium in the subsoil by heavy fertilization. Also, there should be little loss of potash fertilizer in the Penn soil.

In the Berks soil the applied potassium did not all remain in the surface layer. As a rule these soils contain considerable small rock or shale fragments and have a very rolling topography. Because of this it is doubtful if the sorption complex came in contact with all the potassium solution as it moved downward. The second layer showed considerable gain in its exchangeable potassium. In the third layer either there was very little absorbed, or it had not moved into this area. These results indicated that the Berks subsoil can be considerably enriched by potassium applications to the surface. The use of moderate amounts of potash on this soil should be profitable.

In the Hagerstown clay loam soils the applied potash was practically all retained in the first 6-inch layer. When the high exchange capacity as given in Table 2 is considered, the movement of the potassium ion in this soil should not be expected to be rapid. With the larger amount of this available element, it is doubtful if the need of potash fertilization is as great as it is in the other soils. On the other hand, a very heavy application of potash would probably be required to increase the amounts in the subsoil.

Some of these soil samples were sent to the potash laboratory at Purdue University. There Mr. M. H. Thornton determined the available potash by the Neubauer method The milligrams of soluble potassium obtained by this method was calculated to pounds per

TABLE 3.—*The influence of fertilizer treatment on the amount of exchangeable potassium and that obtained by the Neubauer method in the first 18 inches of soil by 6-inch depths.*

Fertilizer treatment	Potassium added in fertilizer	Potassium found in exchangeable form			Potassium obtained with Neubauer method		
		0–6 in.	6–12 in.	12–18 in.	0–6 in.	6–12 in.	12–18 in.
		Sassafras Sand					
N, KCl	230	205	211	227	130	137	164
Lime, N, KCl	230	318	219	170	220	194	160
N	—	90	85	72	40	61	47
N, KCl	460	210	157	143	179	118	144
		Penn Gravelly Loam					
N, KCl	460	1,058	323	99	574	414	162
Lime, N, KCl	230	636	126	99	540	169	193
N	—	99	49	65	113	127	100
		Hagerstown Clay Loam					
N, P	—	305	167	148	327	295	329
Lime, N, KCl	230	462	186	124	442	268	222
N	—	373	258	304	424	404	441
N, KCl	460	1,769	678	405	788	523	550

acre. These values, as well as the ones secured in the exchangeable procedure, are given in Table 3. On the whole the amount of exchangeable potassium is greater than that indicated available by the Neubauer method. Both methods show an accumulation of potassium with potash fertilization. The Neubauer results indicate also that there was much less potassium available for plants in the sandy soil than in the heavier textures.

The results of this study indicate that light-textured soils are unable to retain large amounts of exchangeable potassium. The subsoils have an even smaller retention capacity. Unless the exchange complex of these soils is increased by incorporating organic matter, potash fertilizer should not be applied in large amounts but more often. The movement of potassium in the heavy-textured soils was much less than in the light-textured soils. The slow movement of this ion is probably due to the high exchange capacity of these soils. This does not necessarily indicate that these soils should receive a large potash fertilization. The movement of this element in the silt loam soils was intermediate between the sandy and clay soils.

EFFECT OF AGE, CONDITION, AND TEMPERATURE ON THE GERMINATION OF FLAXSEED[1]

A. C. DILLMAN AND E. H. TOOLE[2]

THIS paper reports the results of germination tests of flaxseed 4 to 18 years old, of weather-damaged seed, and of seed exposed to high temperatures in the Imperial Valley of California. Flaxseed of good quality and stored under favorable conditions may be expected to maintain its viability for a period of 6 or 8 years. The germination of weather-damaged flaxseed may be seriously impaired, however. Filter[3] reported the germination of three samples of flaxseed, probably fiber flax of only fair quality, as follows:

Age, years	Germination, %			
	Sample No 1	Sample No. 2	Sample No 3	Average
1	91	81	92	88
2	83	80	90	84
3	88	73	91	84
5	80	77	82	80
6	77	68	79	75
8	71	63	67	67
11	53	35	34	41

GERMINATION OF AGED FLAXSEED

The writers obtained 13 samples of seed flax (linseed) grown at the Northern Great Plains Field Station, Mandan, N. Dak., from 1918 to 1929. The seed was stored when air-dry, that is, at about 7 or 8% moisture content, in small lots in metal containers in an unheated seed house at Mandan. It is safe to assume that the relative humidity was low at all times as there was little exchange of air in the metal containers. The summer temperatures in the seed house rarely exceeded 90° F; the winter temperatures at times may have been as low as −20°F.

Germination tests were made in February 1934 and again in June 1936. The tests were made in quadruplicate, on wet blotting paper, in a nearly saturated atmosphere, at alternate temperatures of 20° C at night and 30° C during the day. The germination was completed in from 4 to 7 days. The results are shown in Table 1.

[1]Contribution from the Divisions of Cereal Crops and Diseases and Seed Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication September 28, 1936.

[2]Associate Agronomist and Physiologist, respectively. The authors wish to express their appreciation of the cooperation of the California Agricultural Experiment Station in obtaining the seed samples reported on in Tables 2 and 3; to Mr. S. O. Sorensen, chief chemist for the Archer-Daniels-Midland Company, Minneapolis, Minn., for the analyses reported in Table 2; and to Professor T. H. Hopper, of the North Dakota Agricultural Experiment Station, for the analyses reported in Table 3.

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TABLE 1.—*The germination of flaxseed grown at Mandan, N. Dak., 1918–1929.*

Sample No.*	Year grown	Germination Feb. 1934		Germination June 1936	
		Age, years	%	Age, years	%
1	1929	4	96	7	99
2	1928	5	98	8	98
3	1927	6	98	9	99
4	1926	7	94	10	92
5	1925	8	94	11	91
6	1924	9	90	12	89
7	1923	10	95	13	96
8	1922	11	94	14	94
9	1921	12	58	15	56
10	1920	13	89	16	89
11	1919	14	55	17	50
12	1919	14	75	17	69
13	1918	15	66	18	58

*Samples 1 to 11 were North Dakota Resistant No 114; samples 12 and 13 were Newland, both varieties of the linseed type.

It will be noted that in 1936 samples 1 to 8 showed a very satisfactory germination after storage for a period of 7 to 14 years. Samples 9 to 13 (15 to 18 years of age) were lower in viability, the seeds germinating from 50 to 89%. Samples 9 and 11, grown in 1921 and 1919, respectively, gave a much lower germination than sample 10, harvested in 1920. This difference may have been caused by drouth in 1919 and 1921 which forced early ripening before the seed was fully mature.

GERMINATION OF WEATHER-INJURED SEED

When flax is exposed to much wet weather after harvest the seed is liable to be injured in germination. This weather injury is evidenced by a darkened or scabby appearance of the seed, a lower test weight, and by the development of rancidity as indicated by a high acid number of the oil.

In 1926, a wet harvest and threshing season in Minnesota and the Dakotas resulted in much weather-damaged flaxseed being shipped to market. Some 3,600 cars of flaxseed received on the Minneapolis market contained from 10.1 to 18.0% of moisture. In early February 1927, a germination test of 41 carlot samples indicated that seed of high moisture content was injured in germination. Ten samples of 9 to 10% moisture content germinated 77.4%; 14 samples of 10.1 to 11.0% moisture, 74.6%; and 5 samples of 11.1 to 13.0% moisture, germinated 61.0%. It is probable that the germination would have been much further reduced if the flaxseed had been stored until summer temperatures occurred.

An unusual case of seed injury occurred in the flax harvested in 1930 at the Imperial Valley Experiment Station, El Centro, Calif. The varietal plats, grown under irrigation, were harvested about May 1 and the crop left in the field until about August 15, when it was threshed. The seed of four varieties examined showed marked weather injury and a low test weight (36.4 to 45.0 pounds per bushel),

and the expressed oil had a high acid number (19.3 to 23.1) as compared with a normal acid number of about 1.0 in oil obtained from sound flaxseed.

The germination of the seed was injured and very poor stands of flax were obtained when the seed was sown in the field. At the time it was thought that the long exposure of the harvested crop to high temperatures may have caused the injury. The summer climate of the Imperial Valley is clear, dry, and hot. In 1930 the mean maximum temperature during June and July was 103° and the maximum 112°, and there were 48 days when the temperature was 100° or over.

The yield and quality of the oil of the weather-injured crop of 1930 and the viability of the seed after 6 years storage is shown in Table 2. For comparison, the data on the normal crop of 1929 are also shown.

TABLE 2.—*Oil content, iodine number, acid number, and germination of four varieties of flax grown at El Centro, Calif., in 1929 (uninjured) and in 1930 when the seed was weather-damaged, probably by exposure to moisture in the field.*

Variety	Oil content %*		Iodine No. (Wijs)		Acid No.		Germination %†	
	1929	1930	1929	1930	1929	1930	1929	1930
Linota ..	34.4	31.2	197	182	0.76	23.1	94	1
Redwing.	36.7	33.4	194	182	0.99	19.8	86	4
Bison	36.4	30.3	182	173	0.88	22.9	87	0
Rio	38.8	32.4	179	168	1.09	19.3	94	9

*Oil content on basis of 8% moisture in seed
†Germination in June 1936

In order to determine the effect of exposure to high temperatures, flax of the Punjab variety was harvested about April 20, 1934, and a few sheaves were left in the field, samples being threshed at 15-day intervals from May 1 to August 15. The experiment was repeated in 1935 but modified to include two lots of flax in one of which the sheaves were exposed in dry condition and in the other the sheaves were wet thoroughly and then placed in the open sunshine. No rain occurred during the periods of exposure. In 1934 the mean maximum temperature for May was 98.5°, June 96.6°, July 109.5°, and August 107.8° F. A maximum of 117° was recorded in July and August. In 1935 the mean maximum temperature for May was 90.8°, June 106.6°, July 105.7°, and August 103.7°F. A maximum of 113° was recorded in June and July and 115° in August. The results of the experiment are recorded in Table 3.

It will be seen by reference to Table 3 that flax exposed in a dry condition in the sheaf to the high summer temperatures of the Imperial Valley was not injured in germination nor in the yield and quality of oil. Even when the sheaves were thoroughly wet and then exposed there was little if any injury as found in experiment 2 of 1935. The wet sheaves evidently dried out rapidly before any appreciable injury had been done to the quality and germination of the seed. It may be concluded, as already determined by the experience

TABLE 3.—*Germination, oil content, iodine number, and acid number of flaxseed of the Punjab variety exposed in the sheaf to high temperatures at El Centro, Calif., in 1934 and 1935.**

Dates of threshing	Crop of 1934				Crop of 1935							
					Flax dry				Flax wet and exposed			
	Germination %	Oil %	Iodine No.	Acid No.	Germination %	Oil %	Iodine No.	Acid No.	Germination %	Oil %	Iodine No.	Acid No.
May 1	99	40.3	188	0.29	—	—	—	—	—	—	—	—
May 16	99	41.4	189	0.36	96	41.8	191	0.51	—	—	—	—
June 1	99	41.8	190	0.34	97	41.2	190	0.50	96	40.0	188	0.52
June 16	99	42.1	189	0.34	—	—	—	—	—	—	—	—
July 1	95†	38.0	181	0.60	99	40.5	189	0.45	97	40.6	188	0.98
July 16	98	42.1	190	0.44	—	—	—	—	—	—	—	—
Aug. 1	99	42.1	189	0.38	98	40.5	188	0.47	97	40.9	188	0.46
Aug. 16	98	41.7	188	0.34	—	—	—	—	—	—	—	—

*The flax was harvested about April 20 and left exposed in the field and samples threshed at intervals until midsummer.

†This sample was injured in threshing. In some seeds the tips of the cotyledons were broken as found in the germinating seedlings. The injury is evident also in the lower oil content, lower iodine number, and higher acid number, which indicates that some oxidation of the oil had occurred.

of farmers, that flaxseed of the Punjab variety grown in the Imperial Valley is of high quality and thoroughly satisfactory for sowing.

The experiments reported in Table 3, however, do not explain the cause of the poor quality of the flaxseed harvested at the Imperial Valley Experiment Station in 1930. It seems probable that the crop of 1930 was subjected to some unknown injurious condition, such as exposure of the sheaves on wet soil, injury of seed in threshing, or high humidity at time of threshing and early storage. It is known that flaxseed of high moisture content will deteriorate rapidly in quality and viability when exposed to high temperatures even for a short period of time.

EFFECT OF SOIL TEMPERATURE ON GERMINATION

In the Imperial Valley it is the practice to sow flax the latter part of October or early November. At this season the soil has become cool enough so that weeds will sprout and can be destroyed by cultivation prior to seeding. Seeding earlier than October cannot be recommended from the standpoint of weed control nor from the standpoint of germination of flaxseed.

In a date-of-seeding experiment at the Imperial Valley Experiment Station, El Centro, Calif., flax sown September 20, 1935, gave very poor stands, whereas that sown October 20 and at later dates produced perfect stands. Daily air temperatures of near or over 100° F prevail during September, and it is likely that surface soil temperatures of 100° to 130° occur almost daily during the month of September. It is known that flaxseed does not germinate well at high temperature.

In order to determine the effect of high temperatures on the germination of flaxseed under controlled conditions, tests were conducted as follows: At constant temperatures of 30° and 35° C, and at alternating temperatures of 20° and 30° C, 25° and 35°C, 25° and 40°C, 40° and 20° C, and 40° and 25° C. The first named temperature was the night period of about 18 hours, the second was the day period of about 6 hours. The results are reported in Table 4, and the appearance of the sprouting seeds is shown in Fig. 1.

TABLE 4.—*Germination of Punjab flaxseed at different constant and alternating temperatures.*

Test No.	Temperature, °C	Germination after 2 days, %	Germination after 9 days, %	Condition and length of root sprouts at end of 2 days
1	30°	100.0	—	Normal, 2½ to 4 cm.
2	35°	85.5	97.5	Thickened, short, ½ to 1 cm.
3	20°-30°	97.5	98.0	Normal, ¾ to 1½ cm.
4	25°-35°	99.5	—	Normal, ¾ to 1½ cm.
5	25°-40°	0.0	None	Germination started. Sprouts short, thick, very abnormal.
6	40°-20°	0.0	None	Germination started, but sprouts abnormal, dark and watery.
7	40°-25°	0.0	None	Same conditions as test 6.

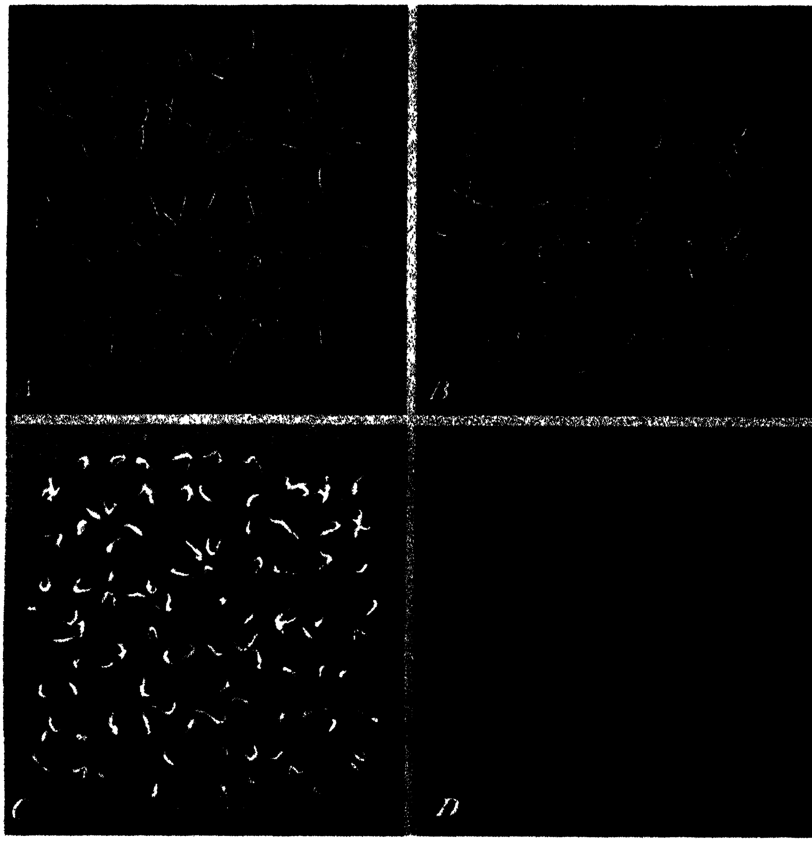

FIG. 1.—The germination of Punjab flaxseed on wet blotting paper after 2 days at the following temperatures: A, 20° and 30° C, showing normal root sprouts; B, 35°C constant temperature, showing thickened abnormal sprouts; C, 25° and 40° C, showing slow germination with short abnormal sprouts; and D, 40° and 25° C, showing no germination. The first-named temperature is for the night period of about 18 hours, the second the day temperature of about 6 hours.

It was thought that germination in soil might possibly show better results than on wet blotting paper. Therefore, germination tests were conducted in sterilized soil at the same controlled temperatures as reported in Table 4. In these tests good germination and normal growth of the seedlings was obtained at a constant temperature of 30° C. At 35° C and at alternating temperatures of 25° and 40° C (40° for 6 hours each day) germination was somewhat slower than at 30° C. However, quite normal seedlings finally developed in the soil tests in contrast to the very poor germination at the same temperatures on wet blotters. Further tests in sterilized soil at a constant temperature of 40° C and at alternating temperatures of 40° and 25° C and 40° and 20° C (40° for 18 hours) resulted in complete failure of germination.

It is evident from these results that a constant temperature of 35°C (95° F) or a temperature of 40° C (104° F) for a period of 6 hours each day will prevent the normal germination of flaxseed on wet blotting paper. A somewhat stronger germination occurs in sterilized soil at these temperatures. The results appear to explain the failure to obtain a satisfactory stand of flax sown at El Centro, Calif., September 20, 1935 when soil temperatures must have been well over 100° F.

ERADICATION OF BINDWEED IN BLUEGRASS LAWNS[1]

R. C. KINCH AND F. D. KEIM[2]

MUCH experimental work has been done on the eradication of bindweed or small-flowered morning glory (*Convolvulus arvensis* L.). Most of this work has been based on experiments in cultivated fields. The literature concerning the eradication of bindweed in grasslands, particularly lawns, is very meager. It is the purpose of this paper to present some of the more important results of a 2 years' study of the eradication of bindweed in lawns at the Nebraska Experiment Station.

Barrett and Hansen (1)[3], in a review of literature on chemical weed control, suggest that sodium chlorate combines more of the desirable qualities of a chemical weed killer than any other herbicide now known. Crafts (2) suggests that the toxic effect of sodium chlorate can be controlled by irrigating the area after application, although in his tests much more sodium chlorate was required for complete eradication with irrigation than was required without it. Vogel (6) reported that sodium chlorate applied to bindweed-infested brome grass pasture killed the grass before the bindweed was greatly injured. Grau (3) found that 1- to 2-pound applications of sodium chlorate per square rod on golf courses under New Jersey conditions gave good control of the plantains (*Plantago* spp.) chickweed (*Stellaria* spp.), crabgrass (*Digitaria sanguinalis* L. Scop.), and many other weeds, without seriously injuring the turf grasses. Rowley (5) found that two sprayings of a 10% solution of sodium chlorate in the fall of the year decreased quackgrass about 77% and increased bluegrass 36%. No results have been reported concerning the removal of bindweed plants at frequent intervals from a grassland area.

METHODS OF INVESTIGATION

Any method of eradicating bindweed from a lawn should preferably be so designed that the bluegrass or other desirable grasses will remain in good condition throughout the treatment. In the investigations herein reported, five such basic methods, with variations were used, as follows: (a) Individual plants were removed by hand at intervals of 1, 2, 3, and 4 weeks; (b) individual plants were treated with 2-, 5-, and 10-gram amounts of dry sodium chlorate; (c) dry sodium chlorate was applied to individual plants after pulling and after spudding; (d) individual plants were lightly sprayed with solutions consisting of ½, 1, and 2 pounds of sodium chlorate per gallon of water; and (e) dry sodium chlorate was applied at the rate of ½, 1, and 2 pounds per square rod and immediately leached into the soil by watering.

These experiments were begun in the spring of 1934 on a heavily infested bluegrass lawn at Lincoln, Nebr. The soil was a Waukesha silt loam. A heavy infestation of bindweed was known to exist at least 4 years previous to the beginning of the experiment. Small flat-topped stakes, level with the soil surface, were used to mark the plats. A total of 16 variations of the five basic methods were

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[3]Figures in parentheses refer to "Literature Cited", p. 38.

used. Each variation was duplicated and is reported in the following tables as an average from two square-rod plats. All of the bindweed plants outside of the experimental plats for a distance of 20 to 30 feet were given an individual treatment of 10 grams of sodium chlorate. By fall of the first year no bindweed plants could be found in that area.

PLANTS REMOVED BY HAND

The first basic method of bindweed eradication in a lawn was an attempt to approximate the field method of eradication by clean cultivation. Plats were gone over at intervals of 1, 2, 3, or 4 weeks and all of the bindweed plants removed. The time required to find and remove the plants in each square rod was recorded, along with the number of plants.

Table 1 indicates that the bindweed was completely killed in a season and a half by removing the plants at weekly intervals. Removing the plants at bi-weekly intervals required two whole seasons of work, but complete eradication was accomplished. The number of plants reappearing was reduced considerably when the plants were removed at intervals of 3 or 4 weeks, but eradication was not accomplished in 2 years. The bluegrass was not injured by this method of eradication. Pulling the plants every week gave complete kill in about the same length of time as clean cultivation, as reported by Kiesselbach, Petersen, and Burr (4). The time required to find and remove all of the plants from a square-rod area during the period required to kill the plants was a little less than 6 hours When calculated at 25 cents per hour, the cost of eradication would amount to about $1.50 per square rod.

DIFFERENT AMOUNTS OF SODIUM CHLORATE

Three different amounts of dry sodium chlorate were applied to the base of bindweed plants to determine the effect of the sodium chlorate on the bindweed and the bluegrass. The plats involved in this experiment had a good stand of bluegrass and were watered frequently. A small dipper with markings so that 2-, 5-, and 10-gram amounts of sodium chlorate could be measured, was used to apply the chemical. Thirteen days after the first treatment was made, five dead plants were selected at random from the plats which received the 5- and 10-gram treatments. These plants were carefully dug and the depth to which the rootstocks were killed was recorded. The effect of the 2-, 5-, and 10-gram amounts of sodium chlorate on the bluegrass was determined by measuring the diameters of 10 dead areas of grass selected at random from each plat. These measurements were taken 1 month after the first treatment was made.

The data recorded in Table 2 show that eradication was accomplished in 1 year by treatment of individual plants with 5- and 10-gram amounts of sodium chlorate. The 2-gram amount did not kill all of the plants back to the ground on the first application and more treatments were required for complete eradication than with the 5- and 10-gram amounts. No plants were dug up from the plat treated with the 2-gram amount. The 5-gram amount killed the

TABLE 1.—*Effect of pulling bindweed plants, from square rod plats in an infested bluegrass lawn at various intervals, on the number of plants reappearing and the length of time required for eradication.*

Date pulled	Intervals at which bindweed plants were removed							
	One week		Two weeks		Three weeks		Four weeks	
	Plants present, number	Time required in pulling, minutes	Plants present, number	Time required in pulling, minutes	Plants present, number	Time required in pulling, minutes	Plants present, number	Time required in pulling, minutes
				Season of 1934				
June 2	411	28	392	23	237	16	194	14
June 9	82	8						
June 16	272	18	252	15				
June 23	296	22			350	28		
June 30	335	33	318	25			254	17
July 7	219	22						
July 14	227	18	270	18	396	26		
July 21	136	14						
July 28	146	15	194	15			170	13
Aug. 4	145	14			236	14		
Aug. 11	176	15	274	18				
Aug. 18	162	13						
Aug. 25	136	13	236	19	380	26	190	13
Sept. 1	50	8						
Sept. 8	83	15	233	28				
Sept. 15	42	6			381	51		
Sept. 22	44	14	178	30			230	40
Sept. 29	28	10						
Oct. 6	21	9	46	16	264	59		
Oct. 13	18	8						
Oct. 20	8	7	31	13			73	13
Oct. 27	5	4			2	5		
				Season of 1935				
May 28	3	4	26	14	209	34	164	38
June 4	4	8						
June 11	1	7	15	12				
June 18	5	7			170	35		
June 25	1	4	18	8			113	24
July 2	1	4						
July 9	—		13	10	183	28		
July 16	—							
July 23	—		8	7			122	29
July 30	—				149	30		
Aug. 6			6	5				
Aug. 13								
Aug. 20			4	9	78	28	67	24
Aug. 27								
Sept. 3			2	5				
Sept. 10					43	21		
Sept. 17							54	16
Oct. 1			1	4	28	12		
Total	3,057	348	2,517	294	3,106	413	1,631	241

TABLE 2.—*Effect of 2-, 5-, and 10-gram amounts of sodium chlorate on bindweed and bluegrass when applied to bindweed plants in an infested bluegrass lawn.*

Date treated	Number of plants treated with		
	2-gram application	5-gram application	10-gram application
	Season of 1934		
July 12	93	266	100
July 26	47	17	18
Aug. 9	29	14	8
Aug. 23	14	8	2
Sept. 6	3	3	—
Sept. 20	3	—	3
Oct. 4	3	3	—
Oct. 18	—	2	—
	Season of 1935		
June 4	1	—	—
June 18	2	—	—
July 9	1	—	—
July 23	—	—	—

plants to an average depth of 2 7 inches, while the 10-gram amount killed the plants to an average depth of 12 inches. The ground was moist but not wet when the sodium chlorate applications were made. No moisture was received during the 13 days.

The area of dead grass killed by the 2-gram amount averaged 1.9 square inches, and the areas killed by the 5- and 10-gram amounts averaged, respectively, 14 9 and 25.0 square inches. In a well-kept lawn a 2-square-inch area of dead grass is hardly noticeable. A 15-square-inch area shows up plainly, but a 25-square-inch area plainly exposes an area of dead grass which is surrounded by an area of yellowed grass.

DRY SODIUM CHLORATE APPLIED TO INDIVIDUAL PLANTS

The third basic method of bindweed eradication was the application of 5 grams or about ½ teaspoon of dry sodium chlorate to individual bindweed plants every 2 weeks. The following variations of the treatment were used: (a) Plants were pulled and the sodium chlorate placed on the crown, and (b) plants were spudded with a dandelion spudder about 1½ inches below the surface and the sodium chlorate placed in the hole on the cut part of the rootstock.

The data in Table 3 show that complete eradication was accomplished in one season by 5-gram applications of sodium chlorate to individual plants. This is in accordance with the data reported in Table 2. The appearance of old plants during the second season was carefully watched but none were found; however, several small seedlings were found and eliminated. There was practically no difference between the two methods in their effect upon the bindweed.

Small areas of bluegrass were killed wherever the sodium chlorate was applied. Where sodium chlorate was applied to the crown of the plant at the surface, an area of grass 4 to 5 inches in diameter was

TABLE 3.—*Effect of removing bindweed plants, from square rod plats in an infested bluegrass lawn and placing 5 grams of sodium chlorate on the crown or in the hole made by the spudder, on the number of plants reappearing and the length of time required for eradication.*

Date treated	Plants pulled out and sodium chlorate added		Plants spudded out and sodium chlorate added	
	Plants present, number	Time required for treatment, minutes	Plants present, number	Time required for treatment, minutes
	Season of 1934			
June 2	160	25	150	34
June 16	6	2	5	2
June 30	16	3	12	3
July 15	10	2	2	1
July 28	7	2	1	1
Aug. 11	5	1	1	1
Aug. 25	10	3	7	1
Sept. 8	4	2	—	—
Sept. 22	2	3	2	3
Oct. 6	1	2	2	3
Oct. 20	2	3	—	—
	Season of 1935			
June 7	—	—	—	—
Total	223	48	182	49
Total lbs. sodium chlorate used	2.5		2.0	

killed. Where the sodium chlorate was put 1½ inches in the ground, an area of grass 2 to 3 inches in diameter was killed. These experimental plats did not receive any moisture either by rain or sprinkler for nearly 2 months and the sodium chlorate remained near the surface in close contact with the grass. This was probably why such large areas of bluegrass were killed.

A further study of the spudding and sodium chlorate method of eradication was made. A large bindweed-infested bluegrass lawn that was watered heavily about every 2 weeks was used for the experiment which was started in July of 1934. Over 4,500 plants were removed and treated the first time. The lawn was treated four more times at 4-week intervals that summer. There was no relation between the time of watering and the time of treating. Only 124 plants were found in the last treatment of 1934 and most of them were plants that had been missed at previous treatments. A number of small spots of yellowed grass appeared in the lawn that summer, each of which had a circular area of dead grass ½ to 2 inches in diameter in the center of it. On May 15 of the next year (1935) only 17 bindweed plants could be found in the lawn. By the middle of July, after the lawn had received three additional treatments, no bindweed plants could be found. The bluegrass had completely reclaimed the dead and yellowed areas of the previous season.

SODIUM CHLORATE SOLUTION SPRAYED ON BINDWEED PLANTS

Sodium chlorate solutions of ½, 1, and 2 pounds to the gallon of water were sprayed lightly on the bindweed plants in a group of square-rod plats. The variations of the spray treatment comprised the fourth basic method of bindweed eradication in lawns. A small quart-size sprayer was used to spray the solutions on the plants in a fine mist. The plants were sprayed every 2 weeks during the two seasons until all the plants were killed.

It can be seen from Table 4 that complete eradication was accomplished by spraying the plants with all the sodium chlorate solutions used. There was very little difference in the effect of the various concentrations. Since the solutions were sprayed only on the plants, a very small amount of sodium chlorate was required. The bluegrass was able to withstand two or three such sprayings without much injury, but where a bindweed plant repeatedly sent up new shoots in about the same spot, a small circular area of bluegrass 2 to 3 inches in diameter was killed by the repeated sprayings. In the fall of the second year (1935), the bluegrass had reclaimed most of the dead areas.

SODIUM CHLORATE APPLIED DRY AND IMMEDIATELY LEACHED IN THE SOIL

In this basic method of bindweed eradication, an effort was made to get sufficient sodium chlorate below most of the grass roots to have a toxic effect upon the bindweed rootstocks without materially injuring the grass. Dry sodium chlorate was broadcast on respective plats by hand at the rate of ½, 1, and 2 pounds to the square rod per application. The plats were thoroughly watered immediately after the applications were made. No definite check was made on the amount of water applied to the plats but a large sprinkler was allowed to remain in one place for 3 hours before moving to the next Five applications of sodium chlorate followed by waterings were made at 2-week intervals during the summer of 1934. Counts of the bindweed plants in the plats were made just before the chemical was applied, but no plants were removed. The density of the bluegrass stand was estimated at various times throughout the time of the experiment. Applications were made the next year (1935) only where it was deemed necessary.

Complete eradication of all the bindweed plants is shown in Table 5 where ½-, 1-, and 2-pound amounts of sodium chlorate per application were broadcast and immediately leached into the soil. Not only were the bindweed plants eradicated, but dandelions, crabgrass, yellow sorrel, and spotted spurge disappeared from the plats. The ½-pound application had no apparent effect upon the bluegrass, while the 1-pound application killed a small amount. The 2-pound application killed most of the grass, and the grass that remained alive had a decidedly yellow color. The maintenance of a 100% stand of bluegrass even when a total of 3 pounds of sodium chlorate

TABLE 4.—*Effect of spraying solutions of ½, 1, and 2 pounds of sodium chlorate to the gallon, on bindweed plants in an infested bluegrass lawn, on the number of plants reappearing and the time required for eradication.*

Date sprayed	½ lb. to gallon			1 lb. to gallon			2 lbs. to gallon		
	Plants present, number	Time required for spraying, minutes	Amount of solution used, pints	Plants present, number	Time required for spraying, minutes	Amount of solution used, pints	Plants present, number	Time required for spraying, minutes	Amount of solution used, pints
				Season of 1934					
June 21	124	16	1	110	9	1	102	8	1
July 5	110	9	½	69	6	¼	58	5	¼
July 19	101	9	1	65	5	½	52	4	¼
Aug. 2	107	10	1	68	5	¼	37	3	¼
Aug. 16	121	9	¼	81	6	½	27	3	⅛
Aug. 30	66	5	¼	31	3	¼	10	1	$\frac{1}{16}$
Sept. 13	48	5	¼	41	4	¼	4	1	$\frac{1}{16}$
Sept. 27	17	3	⅛	19	3	$\frac{1}{16}$	2	2	$\frac{1}{16}$
Oct. 11	3	2	$\frac{1}{16}$	17	3	$\frac{1}{16}$	—	—	—
Oct. 25	—	—	—	8	2	$\frac{1}{16}$	—	—	—
				Season of 1935					
June 7	5	6	$\frac{1}{16}$	1	4	—	1	5	$\frac{1}{16}$
June 21	3	4	$\frac{1}{16}$	1	4	$\frac{1}{16}$	1	5	—
July 5	2	4	$\frac{1}{16}$	1	4	—	—	—	—
July 9	—	—	—	—	—	—	—	—	—
Total	707	82	$4\frac{5}{8}$	512	58	$3\frac{3}{8}$	294	37	$2\frac{3}{16}$
Total lbs. sodium chlorate used		0.6			0.8			1	

had been applied is noteworthy, since considerable bluegrass outside of the experimental plats, that had not been watered and treated with sodium chlorate, succumbed to the severe drouth of 1934.

TABLE 5.—*Effect of broadcasting and leaching into the soil ½, 1, and 2 pounds per square rod of sodium chlorate on bindweed plants and bluegrass when broadcast on square rod plats in an infested bluegrass lawn at 2-week intervals.*

Date treated and counted	½ lb. to sq. rod		1 lb. to sq. rod		2 lbs. to sq. rod	
	Amount sodium chlorate used, lbs.	Plants present, number	Amount sodium chlorate used, lbs.	Plants present, number	Amount sodium chlorate used, lbs.	Plants present, number
			Season of 1934			
June 25	½	—	1	—	2	—
July 4	½	169	1	101	2	117
July 18	½	181	1	118	2	112
Aug. 1	½	174	1	109	2	112
Aug. 15	½	184	1	176	2	79
Aug 29	—	157	—	133	—	34
Sept. 12	—	166	—	134	—	26
Sept. 26	—	133		73	—	10
Oct. 12	—	73	—	47	—	3
			Season of 1935			
June 12	½	14		—	—	—
June 26	—	2		—	—	—
July 10	—	—	—	1	—	—
July 24		—	—	—	—	—
Aug. 7	—	8		—	—	—
Aug. 21		—	—	—	—	—
Total lbs. sodium chlorate used	3		5		10	
			Estimated percentage of bluegrass present in the plats			
Oct. 12, 1934	100		80		30	
Aug. 21, 1935	100		90		40	
May 1, 1936	100		100		75	

DISCUSSION

Bindweed plants growing in a lawn did not seem to have the vigor and recuperative power of plants growing in a cultivated area. This undoubtedly had a great deal of influence on eradication results. On the other hand, when the bindweed plants were pulled, they broke off from the crown at or near the surface of the ground. Apparently the combination of reduced plant vigor and breaking off the plants at or near the surface had about the same rootstock starvation effect as cutting of the shoots 4 inches below the surface in a cultivated field every week as reported by Kiesselbach, Petersen, and Burr (4).

The number of bindweed plants that reappeared from week to week varied a great deal, according to conditions. Moisture was the principal factor in the variation of the number of plants reappearing, although it had no noticeable effect upon the time required for eradication.

Sodium chlorate was very effective in eradicating bindweed from a lawn. The action of the sodium chlorate on the bluegrass was severe where no effort is made to control its action. Thorough waterings of a lawn just after applying the sodium chlorate seemed to leach down enough of the chemical so that it would not materially injure the grass. In a well-watered lawn, areas of grass that had been killed by sodium chlorate were very quickly repopulated by bluegrass. This indicates that the soil sterilizing effect of sodium chlorate can be controlled by watering as far as the growing of bluegrass is concerned. Observations in the summer of 1935 revealed that treated bluegrass areas were slightly more susceptible to drouth than untreated areas.

SUMMARY

Eradication of bindweed in a lawn was attempted by pulling the plants at weekly intervals. When plants were pulled at weekly intervals, one season and a half and a total of 28 treatments were required for complete eradication. When the plants were pulled at 2-week intervals, two entire seasons and a total of 20 treatments were required for complete eradication. Pulling at 3- and 4-week intervals for 2 years failed to eradicate the plants. The cost of eradicating the bindweed by pulling averaged from $1.25 to $1.50 per square rod.

Light sprayings on individual bindweed plants with sodium chlorate solutions of ½, 1, and 2 pounds to the gallon at 2-week intervals gave complete eradication. There was very little difference in effect of the three concentrations. Areas of grass 2 to 4 inches in diameter were killed by the repeated sprayings of one place where bindweed plants kept coming up.

Individual treatment of bindweed plants with a 5-gram amount of sodium chlorate gave complete eradication in one season. When the lawn was thoroughly watered after the applications were made, the bluegrass was injured but very little.

Broadcasting sodium chlorate and immediately leaching it in the soil by applying water killed the bindweed in a year's time and left the bluegrass relatively uninjured. A total of 5 pounds of sodium chlorate applied in 1-pound applications at 2-week intervals gave the best results.

Sodium chlorate has a toxic action on the bluegrass, but the action was controlled by watering. Small areas of bluegrass killed by the sodium chlorate were very quickly repopulated by the bluegrass if the ground was thoroughly watered.

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RATE OF WATER LOSS IN WHEAT VARIETIES AND RESISTANCE TO ARTIFICIAL DROUTH[1]

B. B. BAYLES, J. W. TAYLOR, AND A. T. BARTEL[2]

DROUTH is a very important factor in limiting cereal production in the United States. A large proportion of the cereal acreage in this country is grown in the more arid regions where cereals are better adapted than most other crops, and where drouth frequently occurs. Periods of drouth at some time during the growing season are also common in the more humid areas.

Escape from and tolerance of drouth should not be confused with drouth resistance. Drouth escape results from such a rate of growth or time of maturity as enables plants to complete their growth when drouth is not severe. In the present experiments varieties were selected that head at approximately the same time, so the differences would seem to be due to true resistance rather than escape from drouth. Drouth tolerance results from the capacity of such plants as sorghum and many desert species to become more or less dormant and later to renew active growth when growing conditions are more favorable. Drouth tolerance seldom is of importance in wheat, especially in the regions of winter rainfall.

It would seem that the ability of wheat plants to produce grain under drouth conditions might be due to two somewhat distinct phenomena, *viz.*, (a) the ability to limit transpiration and to carry on the processes of photosynthesis and assimilation under conditions conducive to high evaporation and (b) the ability of the root systems to take in moisture as fast as or faster than it is transpired. It would seem logical that varieties and species might differ in one or both of these respects and also in resistance to high temperatures.

The development of Hope wheat with its resistance to stem rust led to the belief that spring wheat production would become less hazardous. However, the susceptibility of Hope to heat or drouth, or both, made it unpopular as a commercial wheat and emphasized the necessity of developing varieties combining drouth and heat resistance with rust resistance. Accordingly, experiments were conducted with the object of finding a usable method for evaluating varieties for drouth and heat resistance. As the study of roots is very tedious and rather difficult and so far has been unsatisfactory, only the aboveground parts of plants have been studied in the present investigations.

REVIEW OF LITERATURE

The work on the water requirement of plants by Briggs and Shantz (3, 4)[3] and others has given a background for further investigation of drouth resistance but has not explained what constitutes drouth resistance or given a measure of

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the drouth resistance of different varieties or crops. Such water requirement studies have measured merely the rate at which plants transpire water with an optimum soil moisture content and not the ability of plants to grow and produce crops under drouth conditions. Maintenance of a uniform distribution of moisture through the soil mass has not been accomplished satisfactorily and, as a result, very little work has been done in determining the water requirement of varieties or species of plants grown in soils with a low moisture content.

Newton and Martin (7) reported studies on the relation of the hydrophilic colloids in plant tissues (as measured by bound water) to drouth resistance, but this method used alone has not been found satisfactory in evaluating crop varieties.

Martin (6) has shown that sorghum leaves and stalks wilt and dry more slowly than those of corn and suggests that the waxy cuticle of sorghum is largely responsible.

Krasnosel'skaia-Maksimova and Kondo (5), in Russia, have studied the effect of drouth at different stages of plant development by using a drouth chamber with controlled temperature, humidity, and air velocity. The occurrence of drouth during the period from shooting to the end of flowering was most injurious to cereal plants.

Aamodt (1) has described the construction of a drouth chamber used in determining the relative resistance of wheat varieties, and Aamodt and Johnston (2) have presented results on the relative resistance of several spring wheat varieties as determined in this drouth chamber. They found that drouth-resistant varieties possessed a more highly branched primary root system than susceptible varieties.

Nichiporovich (8) studied the rate of water loss from cut plants of many species. He found that many xerophytes lose moisture less readily than other types and that water in special storage tissues is utilized by the cut plants. Mesophytes first show a decrease of transpiration followed by a sharp rise, which gives way to a second decrease. No data were presented on relative rate of water loss in varieties of the same species that have similar morphologic structures.

MATERIALS

Eight varieties of spring wheat that have shown varying ability to yield under dry conditions but which mature at approximately the same time were studied. Baart (C. I. 1697)[4] is commonly accepted as being very drouth resistant. Experiments and farm experience have shown it to be one of the highest yielding varieties under extremely dry conditions such as those at Lind, Wash., and Havre, Mont. Onas (C. I. 6221) has nearly equalled Baart in yield over a period of years at Lind and other dry-land stations. Ceres (C. I. 6900) has replaced Marquis in many sections in the hard red spring area of the northern Great Plains and has given higher yields in the drier sections of this area. Marquis (C. I. 3641) is still the leading variety of hard red spring wheat and was considered one of the best varieties in the drier sections before the introduction of Ceres, which is more resistant to drouth and rust. Hope-Ceres (C. I. 11432) and Hope (C. I. 8178) have shown susceptibility to injury under the dry, hot conditions often encountered in the northern Great Plains. Their yields have not compared favorably with those of other varieties except when severe epidemics of rust have lowered

[4]Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

the yields of other varieties. Huston (C. I. 5208) usually has not given good results outside of the humid valleys of western Oregon and Washington.

Kubanka (C. I. 1440), a variety of durum wheat, has been generally recognized as drouth resistant, although its commercial distribution is largely limited to some of the more humid areas of the spring wheat belt. At the present time none of the durum varieties is grown extensively outside of eastern North Dakota, South Dakota, and Minnesota, and north into Canada, where rust epidemics are of frequent occurrence. The distribution of Kubanka is determined by factors other than ability to produce under drouth conditions.

EXPERIMENTAL DATA

RELATIVE INJURY OF VARIETIES UNDER ARTIFICIAL DROUTH CONDITIONS

The two wheat varieties, Baart and Hope, were used in preliminary studies in the greenhouse at the Arlington Experiment Farm, Rossyln, Va., near Washington, D. C., during the winter of 1931-32. Two plants of each variety were grown in 8-inch pots. The soil in some of the pots was allowed to dry prior to heading of the plants until parts of the plants apparently were dead. Water was then added and within a few days an estimate was made of the percentage of dead tissue. This estimate for the plants of 56 pots was 90 for Hope and 75 for Baart. In another experiment drying continued until the plants suffered severely from lack of water. Three of 22 plants of Baart and 8 of 22 plants of Hope did not recover on watering.

Plants of eight varieties were grown similarly, two varieties to a pot. Each variety was paired in turn with each of the others. Roots of the paired varieties were thus in soil having the same moisture content. When the plants were at the shooting stage the soil was brought to its maximum moisture-holding capacity and the pots, 28 at a time, were placed on a revolving table over which a current of hot air, 92° to 98° F, was blown from a "unit heater" (a combination of a steam radiator and an electric fan). The unit heater and table are shown in Fig. 1. Exposure for 24 hours was usually sufficient to show differential injury.

The notes on injury are given in Table 1. Hope was again injured considerably more than Baart—81% as compared to 35% for Baart. The difference was plainly visible, as in nearly every pot Hope showed earlier wilting and more rapid death of leaves and tillers than Baart. Other varieties showed some irregularities, possibly because of the small number of plants, but in general the results are in agreement with field observations on the relative resistance of the varieties to drouth.

EFFECT OF SOIL MOISTURE ON WATER CONTENT OF BAART AND HOPE PLANTS

In order to gauge the ability of plants of Baart and Hope to retain water under drouth conditions, their water content was determined with soil moistures varying from optimum to drouth conditions. Two plants of each variety were grown in each 8-inch pot. The varieties thus were subjected to the same soil moisture conditions.

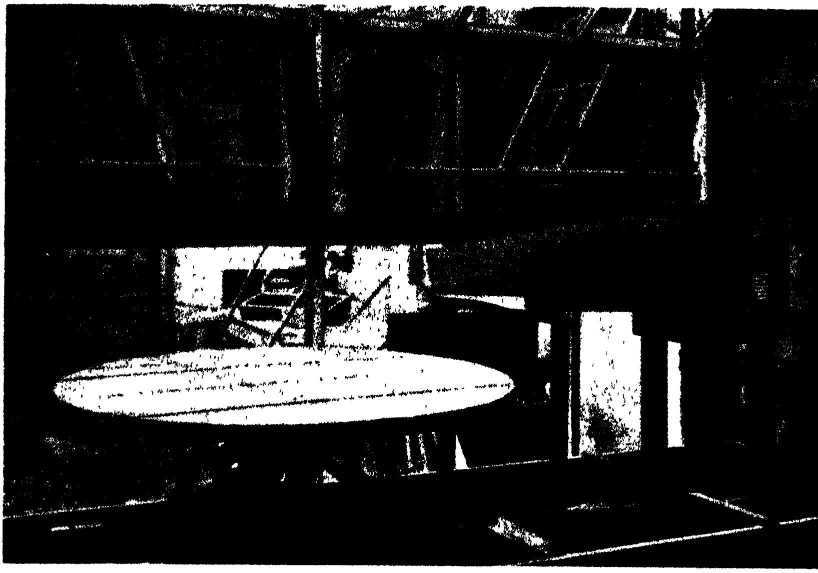

FIG. 1.—Unit heater and revolving table used in producing artificial drouth conditions in the greenhouse.

TABLE 1.—*Relative injury to eight varieties of wheat exposed to a current of air at a temperature of 92° to 98° F*

Variety	Percentage injury		
	Test number		Average
	I	II	
Onas	31	29	30
Baart	37	33	35
Kubanka	52	38	45
Huston	48	52	50
Ceres	73	60	67
Marquis	78	60	69
Hope-Ceres	72	68	70
Hope	81	81	81

The soil moisture was varied by withholding water from the pots for different periods.

The percentage of moisture in plants (with roots removed) is shown in Table 2. With optimum soil moisture, plants of the two varieties had approximately the same moisture content. However, as the soil moisture became deficient, the Hope plants showed a lower percentage of water than the Baart plants.

RATE OF WATER LOSS FROM PLANTS WITH ROOTS REMOVED

If there is a difference in the protoplasmic or morphologic characteristics of varieties making some more resistant to drouth than

TABLE 2.—*Percentage of water in plants of Baart and Hope under varying conditions of soil moisture.*

No. of pots	No. days since last watered	Percentage of water in plants		
		Baart	Hope	Difference between Hope and Baart
5	1	88.4	88.1	0.3
5	1	87.8	88.2	—0.4
5	1	88.9	88.6	0.3
4	6	83.5	81.8	1.7
5	8	78.4	77.7	0.7
4	7	75.5	73.1	2.4
5	9	72.5	69.7	2.8

others, it would seem that a difference in rate of loss of moisture from the plant tissues during drying might be shown. In order to determine if such a difference exists, four plants, two each of Baart and Hope, were grown in each of several 8-inch pots. In addition, the varieties were grown alone, one plant per 6-inch pot. The latter condition eliminates root competition between varieties but does not insure uniform watering for both varieties. When the plants were shooting, but before they had reached the boot stage, they were pulled up, the roots and soil removed, and the plants weighed immediately. They were then placed on frames covered with ¼-inch wire mesh in a laboratory at a temperature of approximately 75° F. A 16-inch electric fan kept the air circulating, but the air current was not turned directly on the plant material. The samples were weighed at intervals and then the final oven-dry weight was determined. The percentages of moisture in the two varieties at different intervals are given in Table 3. The percentages represent averages of 17 plants in the 6-inch pots and 14 plants in the 8-inch pots. In both sets of material the water content of the two varieties was approximately the same at the time they were removed from the soil, but the loss of moisture from Hope was much more rapid than from Baart.

TABLE 3.—*Percentage of water in cut plants of Baart and Hope after different periods of drying.*

No. hours after removal from soil	Percentage of water in plants					
	Baart		Hope		Diff. between Hope and Baart	
	6-in. pots	8-in. pots	6-in. pots	8-in. pots	6-in. pots	8-in. pots
0	89.2	88.3	89.4	87.7	—0.2	0.6
5	86.9	85.6	85.5	83.6	1.4	2.0
22	78.7	77.5	67.5	68.9	11.2	8.6
27	75.3	74.1	62.8	63.2	12.5	10.9
46	64.4	62.0	51.9	48.5	12.5	13.5

EFFECT OF SIZE OF PLANT ON RATE OF WATER LOSS

As the plants of Baart averaged higher in dry weight than those of Hope of the same age, the two varieties of two different ages were grown in pots in the greenhouse. The plants were dried under identical conditions to determine if differences in size of plant might account for the differences in rate of water loss. The results are presented in Table 4. All of the samples contained approximately the same percentage of water when removed from the soil, and the two lots of Baart, one of which had a final dry weight three times that of the other, lost moisture at approximately the same rate. In the case of Hope the smaller plants lost moisture somewhat faster than the larger ones, but a wide difference remained between the large plants of Hope and the small plants of Baart.

TABLE 4.—*Percentage of water in cut plants of Baart and Hope of two ages after different periods of drying.*

No. hours after removal from soil	Percentage of water in plants harvested			
	Near boot stage		At shooting stage	
	Baart	Hope	Baart	Hope
0.0	87.8	88.2	88.4	88.1
2.0	86.9	86.9	87.7	86.9
4.5	86.0	85.5	86.8	85.2
22.5	80.2	74.3	80.6	71.1
26.5	77.8	69.7	78.3	65.7
46.5	66.6	55.3	66.5	51.5
52.5	61.6	50.5	61.2	47.7
72.5	53.5	44.4	51.1	43.8
Dry weight per plant	3.70	1.78	1.30	0.71

Results on the rate of water loss from plants of Baart and Hope in the fourth leaf stage are given in Table 5. Even at this young stage of development when the average oven-dry weight of the 31 Baart

TABLE 5.—*Percentage of water in cut plants of Baart and Hope in the fourth-leaf stage after different periods of drying.**

No. hours after removal from soil	Percentage of water in plants	
	Baart	Hope
0.0	90.7	89.3
2.5	89.2	86.0
6.5	87.9	82.6
9.0	86.8	80.2
24.5	80.5	65.6
47.5	63.6	43.2
74.5	45.5	33.5
Dry weight per plant, grams	0.0697	0.0600

*No tillers were visible in the fourth-leaf stage.

plants was 0.0697 gram and of the 36 Hope plants 0.0600 gram, the difference between the varieties was shown. While differences in size of plants of the varieties did influence the rate of water loss, it was apparently of much less importance than other varietal differences.

RELATIVE RATE OF WATER LOSS OF EIGHT VARIETIES GROWN IN THE GREENHOUSE

Effect of growing conditions.—After the differences in rate of water loss between Hope and Baart were established, determinations were made on eight varieties known from field observations to differ in their ability to produce grain under drouth conditions, and which had shown differential injury when exposed to a current of hot air (Table 1). Four plants, two each of two varieties, were grown in each 8-inch pot and each variety was grown in a pot with every other variety. The material planted November 24, 1933, was grown in greenhouses under four environmental conditions as follows:

High temperature (approximately 75° F):

1. Optimum soil moisture, plants not allowed to wilt before watering; each variety in 21 pots.
2. Deficient soil moisture, plants allowed to wilt before watering; each variety in 21 pots.

Low temperature (approximately 60° F):

3. Optimum soil moisture, plants not allowed to wilt before watering; each variety in 14 pots.
4. Deficient soil moisture, plants allowed to wilt before watering; each variety in 14 pots.

The rate of loss of water from each of the eight varieties, determined when the plants were about 11 weeks old, is shown in Table 6. Fig. 2 shows the rate of loss for material grown with optimum moisture in the low temperature greenhouse. Since determinations were not made for the four sets of material at the same time, comparisons cannot be made between groups. The relative rate of loss for the varieties is approximately the same for the material grown at both temperatures when the plants were given optimum moisture. The spread between varieties is somewhat greater, however, in the material grown under the higher temperatures. This may indicate that the higher temperatures caused the plants of the drouth-resistant varieties to become more hardened to drying than those of the susceptible varieties.

The material grown under the deficient moisture conditions was not so uniform in behavior as that grown under normal conditions because of soil moisture variability in the different pots, which resulted in variation in moisture content of the plants of a variety at the time of harvest. Also, some of the plants subjected to deficient moisture had dead or dying leaves. The rate of water loss of the varieties grown at the two temperatures with optimum moisture ranks them in about the same order as their drouth resistance under field conditions, those with the slower rate of water loss being most resistant.

Effect of drying conditions.—The rates of water loss presented in Table 6 were determined at a temperature of about 77° F. In order to determine if the rate of drying affected the relative loss of water

TABLE 6.—*Rate of water loss from plants of eight varieties of spring wheat grown in greenhouse at two temperatures.*

Variety	Percentage of water in plants after the number of hours indicated				
	0	4	22	28	48
	High Temperature (75°F), Optimum Soil Moisture				
Kubanka	88.8	85.9	75.7	72.3	60.7
Baart	88.6	85.2	70.0	65.4	51.9
Onas	88.6	83.7	65.9	61.5	49.7
Ceres	88.1	83.5	64.5	59.5	43.3
Marquis	88.4	83.8	61.9	56.2	43.9
Huston	87.8	82.6	61.0	56.2	43.4
Hope	88.4	82.5	58.6	53.7	42.8
Hope-Ceres	88.2	81.9	56.7	50.6	38.9
	High Temperature (75°F), Deficient Soil Moisture				
Kubanka	86.5	82.5	69.2	65.9	54.6
Baart	85.4	81.0	64.1	60.2	48.2
Onas	85.0	79.4	57.9	53.1	38.7
Ceres	84.3	78.5	56.6	51.0	36.1
Marquis	84.3	77.5	52.8	48.8	37.6
Huston	85.2	79.4	57.3	52.7	40.1
Hope	84.8	77.8	53.1	48.7	36.2
Hope-Ceres	84.9	77.3	51.6	46.4	32.6
	Low Temperature (60°F), Optimum Soil Moisture				
Kubanka	88.7	85.4	76.4	72.3	63.6
Baart	89.0	85.9	74.4	68.7	60.6
Onas	88.7	84.9	70.8	65.4	56.4
Ceres	89.2	86.2	71.4	66.0	55.7
Marquis	89.1	85.1	69.0	63.5	55.2
Huston	88.1	83.8	68.6	62.6	53.6
Hope	88.4	83.6	64.5	58.7	50.6
Hope-Ceres	88.6	83.8	64.1	58.2	49.4
	Low Temperature (60°F), Deficient Soil Moisture				
Kubanka	85.2	82.2	66.8	63.6	54.4
Baart	84.6	81.3	60.7	55.9	47.3
Onas	85.0	81.1	59.8	55.2	44.2
Ceres	84.6	81.7	63.6	59.0	45.1
Marquis	84.8	81.4	58.4	53.6	44.7
Huston	84.3	81.2	60.1	55.2	45.3
Hope	84.1	80.0	55.2	50.8	42.6
Hope-Ceres	84.5	80.8	51.1	46.5	37.4

of varieties, duplicate sets of plants grown in the greenhouse and harvested at the same time were dried at temperatures of about 60° and 100° F. The rates of water loss of the eight varieties at the two temperatures are shown in Table 7. Ceres shows too rapid loss at 100° F at the 48-hour drying period and it seems likely that this may be due to an accidental loss of leaves from the sample. It will be noted that the results obtained by the slower drying at 60° F are more nearly in accord with those reported in Table 6 than the results from the samples dried at 100° F.

TABLE 7.—*Rate of water loss from plants of eight varieties of spring wheat dried at two temperatures.*

Variety	Percentage of water in plants after number of hours indicated								
	Dried at 60° F					Dried at 100° F			
	0	23	31	49	73	0	23	28	48
Kubanka...	88.7	80.9	78.0	70.2	61.4	89.1	75.5	70.0	57.8
Baart......	89.1	82.3	79.3	68.1	57.5	89.8	72.0	65.4	53.8
Onas........	89.2	82.0	79.1	70.1	58.6	89.8	68.7	61.9	50.9
Ceres...	89.3	82.6	80.1	71.5	60.1	89.8	70.4	62.4	48.8
Marquis...	89.2	82.1	78.8	67.0	55.1	89.5	68.3	61.1	51.4
Huston	88.5	79.3	74.7	60.5	50.5	89.2	68.9	62.2	51.3
Hope......	88.7	79.4	75.0	62.0	50.3	89.1	66.5	54.3	44.4
Hope-Ceres..	89.0	80.4	76.6	65.5	54.3	89.6	69.5	62.2	49.6

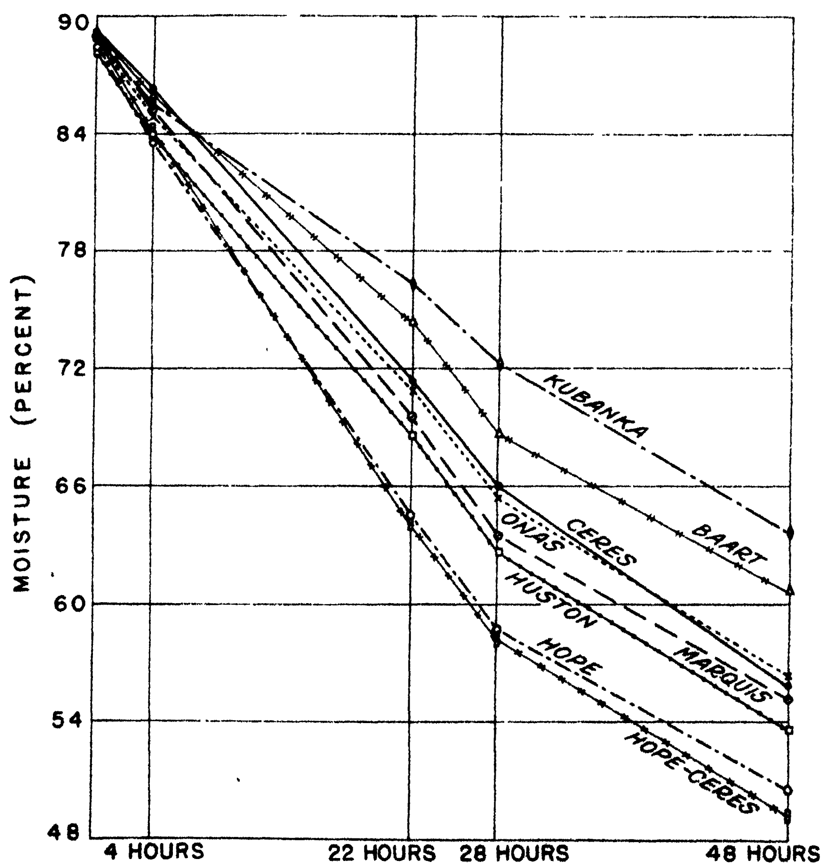

FIG. 2.—Rate of water loss from plants of eight varieties of wheat grown in the low temperature (60°F) greenhouse with optimum soil moisture, 1934.

RELATIVE RATE OF WATER LOSS OF EIGHT VARIETIES GROWN IN THE FIELD

Studies on field-grown material of the eight varieties tested in the greenhouse were conducted in 1934 and 1935 at Tucson, Ariz., Pullman, Wash., and Moro, Ore. Several varieties were studied at each of these stations but, for the purpose of the present discussion, it seems best to present data only on the eight varieties included in the greenhouse tests.

Results from the determinations at Tucson, Ariz., in 1934 and 1935 are presented in Table 8 and Fig. 3. The varieties were grown in nursery rows and the samples were taken for moisture loss before the plants had reached the boot stage. The samples were wrapped in wax paper immediately after pulling. A check showed very little

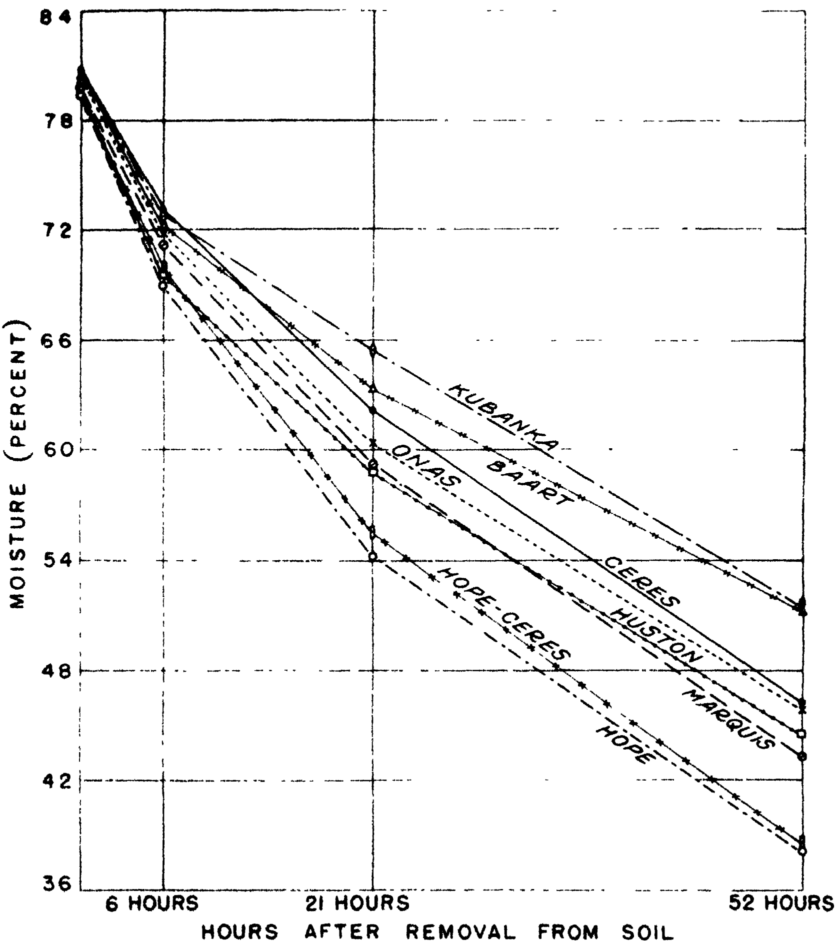

FIG. 3.—Rate of water loss from plants of eight varieties of wheat grown in the field at Tucson, Ariz., 1934 and 1935.

moisture loss in the period between pulling and weighing, which latter was done in the laboratory. The drying technic was similar to that used in the greenhouse. The plats were given normal irrigation and did not suffer for lack of soil moisture. The data presented are averages of three determinations in 1934 and two determinations in 1935. The varieties rank approximately in the same order as in the greenhouse, though the separations are not so distinct. It may be seen that these plants grown in the field had almost 10% less moisture when removed from the soil than plants grown in the greenhouse.

TABLE 8.—*Rate of water loss from plants of eight varieties of spring wheat grown in the field at Tucson, Ariz., Pullman, Wash., and Moro, Ore.*

Hours of drying	Percentages of water in varieties indicated							
	Kubanka	Baart	Ceres	Onas	Marquis	Huston	Hope-Ceres	Hope
				Tucson, Ariz.				
0	79.9	79.9	80.5	80.6	79.9	79.9	79.5	79.4
6	72.9	72.3	73.0	71.9	71.2	69.5	69.9	69.0
21	65.5	63.4	62.2	60.4	59.3	58.8	55.7	54.3
52	51.6	51.4	46.5	45.9	43.5	44.7	38.7	38.3
				Pullman, Wash.				
0	82.9	83.6	83.1	83.4	83.1	83.1	83.2	82.3
7	75.4	70.7	71.4	68.6	69.3	66.0	71.0	69.8
15	60.8	55.2	57.3	49.9	55.4	53.9	54.2	53.7
				Moro, Ore.				
0	80.6	78.8	78.7	78.9	78.4	78.2	78.6	78.5
7	65.6	61.9	62.3	61.4	59.2	56.8	60.3	59.6
11	56.3	53.0	53.9	48.4	51.3	47.1	49.1	49.9
31	47.7	45.7	46.0	38.1	45.6	40.9	40.9	42.7

Results from the eight varieties grown in nursery rows at Pullman, Wash., in 1934 and 1935 are also given in Table 8. The determinations were made each year about July 1 when the plants were about 6 weeks old. The varieties sown at the normal time were heading when these samples were taken and slight variations in the stage of development at that time caused considerable difference in the original moisture content and rate of loss from plants. It was therefore necessary to use the late-sown material which had not reached the boot stage. The results from the younger material, reported in Table 8, are not in very close agreement with those from material grown in the greenhouse at the Arlington Experiment Farm and in the field at Tucson, Ariz. This is especially true of Onas. The plants of this variety, because of late seeding, were much smaller than those of the other varieties. When sown at the normal time for planting the eight varieties head at approximately the same time, but when sown later Onas tends to remain more or less prostrate after the other varieties have started to shoot.

Data for the eight varieties grown at Moro, Ore., in 1934, also are given in Table 8. The samples were taken for determination of mois-

ture loss 5 or 6 weeks after seeding. In these tests Onas again lost moisture more rapidly than would have been expected in relation to the other varieties. The date of seeding at Pullman and Moro was approximately 6 weeks later than the optimum for those localities. This late seeding date and the more rapid rate of drying of the samples may account for the different results obtained.

SUMMARY

Eight varieties of spring wheat with approximately the same relative time of maturity were grown in greenhouses at the Arlington Experiment Farm near Washington, D. C. Two plants each of two varieties were grown in an 8-inch pot Each variety was paired with each of the other seven varieties so as to compensate for variations in soil moisture.

Some of the pots were placed on a revolving table in a current of hot air, 92° to 98° F. Differences in the amount of injury between such varieties as Baart and Hope were clearly demonstrated, but smaller differences between other varieties were not so clearly brought out. In the order of increasing injury the varieties ranked as follows: Onas, Baart, Kubanka, Huston, Ceres, Marquis, Hope-Ceres, and Hope.

The relative rates of water loss from cut plants dried at room temperatures were determined by weighing at intervals. Grown with normal soil moisture the varieties with respect to decreasing rates of water loss were in the following order. Kubanka, Baart, Onas, Ceres, Marquis, Huston, Hope, and Hope-Ceres. When the plants were subjected to low soil moisture, considerable variability was found between the pots and results were not so satisfactory. The evaluation of the varieties from both experiments, however, is consistent with their field performance under drouth conditions.

Rate of water loss determinations were also made of the same eight varieties grown in the field at Tucson, Ariz., Pullman, Wash., and Moro, Ore. Based on the average results for 1934 and 1935 at Tucson the varieties ranked with respect to decreasing resistance to water loss as follows: Kubanka, Baart, Ceres, Onas, Marquis, Huston, Hope-Ceres, and Hope. This order corresponds closely with that established by the material grown in the greenhouse. Results from these same varieties grown at Pullman, Wash., and Moro, Ore., did not conform to this order so closely, especially with respect to the variety Onas, which does not react the same to environment as the other varieties when sown late in the season.

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THE EFFECT OF LATE SUMMER AND EARLY FALL CUTTING ON CROWN BUD FORMATION AND WINTERHARDINESS OF ALFALFA[1]

VAL W. SILKETT, C. R MEGEE, AND H. C. RATHER[2]

THE cutting of alfalfa in late summer and early fall in the northern sections of the United States is frequently practiced, especially when hay is scarce and high priced. A short growing season in this section generally limits the production to two cuttings, but occasionally three or even four cuttings may be taken This at times results in a reduction of the stand due to winterkilling, a decrease in yield the following year, or a combination of both. In Michigan, the third cutting is generally removed in September or October and in southern Michigan where harvesting three cuttings is often the rule, a fourth cutting is sometimes taken late in the fall. It has been observed that these late cuttings have not always resulted in an reduction of stand or yield the following year.

In view of these facts an experiment was laid out to determine the influence of removal of the fall growth of alfalfa at different dates. The experiment dealt not only with the subsequent productivity of the alfalfa following late summer and early fall cutting, but also with the influence of such cutting treatments on crown bud formation and stem production, and the percentage dry matter, rate of respiration, and rate of hardening of the roots.

REVIEW OF LITERATURE

Granfield (4),[3] Garver (2), Moore and Graber (8), Salmon (10), and Kiesselbach and Anderson (6) have shown in general that frequent cutting of alfalfa resulted in a rapid depletion of the stand. Willard, *et al.* (12), state that cutting in late September and early October is likely to be more injurious than cutting on November 1 when no exhaustive new growth can be initiated and after all root storage is complete. Graber, *et al.* (3), show that frequent cuttings reduced the size of the root, lowered root reserves, and reduced the number of crown buds and stems. Peltier and Tysdal (9) found a relationship in 2-year-old alfalfa plants between size of root and number of crown buds and stems and their ability to escape winter injury. Dexter, *et al.* (1), and Megee (7) found that the electrical conductivity method was useful in determining susceptibility of plants to low temperatures and as an indicator of the rate of hardening in alfalfa plants. Steinmetz (11) showed that total solids in the sap and the quantity of juice expressed from alfalfa roots have no apparent relationship to the winterhardiness of the plant.

No attempt has been made to include all the literature citations on low temperature relationships of plants. Harvey (5) has compiled a very complete bibliography on this subject.

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[1]Contribution from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article 271 (n.s.). Received for publication October 16, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 61.

EXPERIMENTAL MATERIAL

In this study a single linear block of plats was laid out on the Michigan State College farm in the summer of 1934 on an established stand of Hardigan alfalfa which provided for five dates of cutting in triplicate and six check plats not cut in the fall. Each plat was 10 x 20 feet and an additional area was cut beyond the end of every plat to insure sufficient material for laboratory studies of the alfalfa roots. The roots were dug at random in each area and selected for uniformity in size and shape.

A similar set of plats was laid out in the fall of 1935 on a 2-year-old stand of Hardigan alfalfa. The same procedure was followed in 1935 as in the preceding year.

EXPERIMENTAL RESULTS

CROWN BUD FORMATION OF ALFALFA AS INFLUENCED BY LATE CUTTING

Following the September and October treatments of 1935, roots were dug at random for the several plats at various times during late fall, washed thoroughly, and crown bud counts made. The buds which had progressed far enough to produce foliage were not considered as buds. The data are presented in Table 1.

TABLE 1.—*The mean number of crown buds per plant from plats of alfalfa cut in the late summer and early fall of 1935.*

Date of cutting, 1935	Mean number of crown buds per plant				
	Nov. 21	Nov 28	Dec. 10	Dec 13	Weighted mean
Check, not cut.	7.9	7.5	10.4	10.7	9.03
Sept. 1 . . .	3.2	4.8	6.8	7.4	5.31
Sept. 15 . . .	7.4	6.6	6.3	8.0	7.03
Sept. 30 . . .	6.6	5.9	9.2	6.3	6.63
Oct. 15 . . .	6.0	6.8	8.0	12.0	8.08
Oct. 30 . . .	6.8	6.8	10.8	9.7	8.00

It will be noted that all plants cut in September, 1935, had fewer crown buds than plants not cut or plants cut in October. The maximum reduction in crown bud formation resulted from cutting on the first of September, whereas little reduction followed the cuttings made in October.

Observations throughout the fall showed that the plants which were not cut developed three distinct sets of crown buds. The first set was formed late in the summer and developed into a short top growth. The second set appeared in November and slowly formed a few foliage leaves. The third set appeared in December and had not developed any foliage at the time of the last observation on December 10. On the other hand, the first set of buds formed by plants cut in early September elongated and became vigorous upright stems. In November, these plants formed fewer crown buds than plants which were not cut and these buds did not elongate. The third set of crown buds noted on the check plants was not formed in this case. Table 2 presents a summary of these observations.

TABLE 2.—*Observations on crown bud formation and subsequent development of foliage during the fall and early winter of 1935.*

Date of cutting, 1935	September	November	December
Check, not cut	Numerous buds developing foliage	Numerous buds developing slight foliage	Numerous buds; no foliage
Sept. 1	Numerous buds rapidly developing extensive foliage	Few buds; no foliage	No buds
Sept. 15.	Numerous buds rapidly developing extensive foliage	Few buds, no foliage	No buds
Sept. 30	Numerous buds slowly developing foliage	Intermediate number of buds developing slight foliage	Few buds, no foliage
Oct. 15	Numerous buds slowly developing intermediate foliage	Intermediate number of buds developing slight foliage	Intermediate number of buds; no foliage
Oct. 30	Numerous buds slowly developing foliage	Numerous buds developing slight foliage	Numerous buds; no foliage

RELATIONSHIP BETWEEN LATE CUTTING OF ALFALFA AND STEM PRODUCTION

In order to determine the effect of late cutting upon stem production and its subsequent relationship to the yield, three counts of the number of stems in 3-foot linear rows were made on each of the 1934 plats. These counts, made after the first hay crop of 1935 was removed, were averaged to obtain a single value for each plat and the values for triplicate plats were then averaged to obtain a mean for each treatment. Thus, a mean for a single cutting treatment represents an average of nine 3-foot lengths. A count of the plants within each of these strips would have been highly desirable, but branching at the crowns and the difficulty of distinguishing individual plants prohibited an accurate study of this phase. The data from the stem counts are presented in Table 3.

TABLE 3.—*The mean number of stems per unit area for each treatment on June 18, 1935, from plants cut during the late summer and early fall of 1934.*

Treatment in late summer or early fall of 1934	Mean number of stems per 3-foot strips on June 18, 1935
Check, not cut	104
Cut Sept. 1	94
Cut Sept. 15	74
Cut Sept. 30	73
Cut Oct. 15	94
Cut Oct. 30	89

The major reduction in stem production occurred when the alfalfa plants were cut on September 15 and 30 of 1934. In 1935, however, the injury occurred toward the first half of September. The probable explanation for this will be presented later.

DRY MATTER AND MOISTURE RELATIONSHIPS OF THE ALFALFA ROOT AS INFLUENCED BY LATE CUTTING

Investigators are generally agreed that the moisture content of plants is highest during the active growing period, decreases to a minimum in the late fall and winter, and increases again when active growth is resumed. Since cutting alters the life cycle of the alfalfa plant, it was necessary not only to determine the effect of late cutting upon the percentages of moisture and dry matter, but also to obtain this information in order to prepare a sound basis for reporting other experimental phases of this problem. Roots of uniform size were used, all samples were weighed to the second decimal place, and in every case the material was dried to constant weight in an electric oven at 90° C. The results are presented in Table 4.

TABLE 4.—*The percentage of moisture and dry matter in the roots of alfalfa plants cut during the late summer and early fall of 1935.*

Dates	Check, not cut		Sept. 1		Sept. 15	
	% dry matter	% water	% dry matter	% water	% dry matter	% water
Oct. 17	42.8	57.2	30.8	69.2	34.2	65.8
Oct. 30	39.0	61.0	28.6	71.4	31.4	68.6
Nov. 14	40.5	59.5	33.8	66.2	33.3	66.7
Nov. 28	38.0	62.0	30.7	69.3	32.2	67.8
Dec. 13	37.0	63.0	31.0	69.0	33.8	66.2
Average	39.4	60.6	30.9	69.1	32.9	67.1

Dates	Sept. 30		Oct. 15		Oct. 30	
	% dry matter	% water	% dry matter	% water	% dry matter	% water
Oct. 17	38.0	62.0	42.3	57.7	41.9	58.1
Oct. 30	34.7	65.3	37.9	62.1	39.5	60.5
Nov. 14	36.1	63.9	36.4	63.6	39.6	60.4
Nov. 28	32.8	67.2	36.5	63.5	36.3	63.7
Dec. 13	36.1	63.9	37.7	62.3	35.6	64.4
Average	35.5	64.5	38.1	61.9	38.6	61.4

The data show that striking differences have been produced by late cutting in dry matter and moisture relationships in the various treatments. In comparison with the check, the roots of plants cut in September have undergone a reduction in the percentage of dry matter and an increase in the percentage of moisture, whereas the

plants cut in October remain very nearly the same as the check As the season progressed, it was interesting to note that the percentage of dry matter found in roots of plants which were not cut and plants cut in October was not maintained but decreased. On the other hand, the percentages for the plants cut in September tend to remain more or less constant. This fact indicates that cutting at critical fall periods modifies unfavorably the moisture and dry matter changes common to winterhardy alfalfa, as found by Megee (7) and others. In view of work previously done by Graber and others, the data also indicate that the new growth, which was initiated by the plant after the September cutting, has drawn upon and reduced the store of energy reserves in the root. Such a condition, indicated by a low percentage of dry matter, increased the susceptibility of the alfalfa plant to injury from low temperatures and reduced the vigor of early growth the following season.

CARBON DIOXIDE LIBERATION OF ALFALFA ROOTS AS AFFECTED BY LATE CUTTING

Carbon dioxide liberation through respiration is an indication of activity in the living plant. Tests were made on alternate weeks during the late summer, fall, and winter in an attempt to determine any relationship which might exist between the activity of vital processes of the plant and late cutting. The first carbon dioxide determinations were made on August 23, before hardening began, and the last determinations on December 10, at a time when the alfalfa plant was in an advanced stage of hardening. Material was prepared by removing the roots from the plat at random, adhering soil was carefully washed away, the dead tops and larger lateral roots were trimmed off, and duplicate 20-gram samples of the roots were placed in 500-cc Erlenmeyer flasks. These flasks were then tightly closed with rubber stoppers fitted with intake and outlet tubes which were closed except when the flask was connected with the apparatus used for the collection of carbon dioxide. The flasks were kept in a dark, cold chamber and held at a temperature approximating that of the soil at the time of sampling.

The train for the determination of carbon dioxide was set up as follows: Potassium hydroxide solution, distilled water, sample flask, sulfuric acid, phosphoric anhydride, ascarite, potassium hydroxide solution, and air pump. Each sample was allotted 5 minutes in the train while the air was being drawn through at a rate sufficient to flush out completely the sample flask three times. The carbon dioxide was collected as it was drawn through an ascarite U-tube of known weight. All weights were made on a chemical balance and were read to the fourth decimal place.

The carbon dioxide determinations, when placed on a dry matter basis, showed that no great difference existed in respiration between plants of the different cutting treatments, and that there was no reduction in any case as the season progressed or as the plant hardened.

EFFECT OF LATE SUMMER AND EARLY FALL CUTTING OF ALFALFA UPON ITS SUSCEPTIBILITY TO INJURY FROM LOW TEMPERATURES

Injury from low temperatures increases the permeability of the plasma membrane of the cell and allows electrolytes to pass out more readily. Electrical conductivity was used to determine the effect of late cutting on the degree of hardening reached by alfalfa plants cut at various dates in the late summer and early fall. Roots of uniform size were selected from plants dug at random from each treatment and thoroughly washed in cold water. The upper 8 inches of the roots were used, with the crown severed and all lateral roots removed. The roots were cut into ¾-inch pieces and, after being thoroughly mixed to insure uniformity, 10-gram samples were weighed out into pyrex test tubes. These samples were frozen by placing the tubes in a slush of alcohol and water inside a refrigeration chamber which was held to a variation of less than 1° C. As the tubes were removed from the slush, 75 cc of distilled water were added to each sample and the tubes were then placed in a 2° C bath in which no temperature variation could be observed with the usual chemical thermometer read to 0.5°. Eighteen to 20 hours were allowed for the electrolytes to diffuse into the surrounding water, after which the electrical conductivity readings were taken by means of a modified Wheatstone bridge. The readings were taken in resistance ohms and were later converted into conductivity by use of the formula

$$\frac{1}{\text{resistance ohms}} = \text{Mhos conductivity}$$

Conductivity is expressed in mhos ($\times 10^{-6}$). After making conductivity determinations, following freezing and exosmosis, the roots were boiled for 30 minutes and electrical conductivity readings were made again, after allowing 18 to 20 hours to elapse for exosmosis to take place. Results from electrical conductivity trials are reported in Tables 5 and 6

TABLE 5.—*The relative injury by freezing of alfalfa roots cut in the late summer and early fall as shown by liberation of electrolytes.*

Date of cutting, 1935	Mhos ($\times 10^{-6}$) per gram of dry matter				
	−3° Oct. 17	−3° Oct. 30	−8° Nov. 14	−8° Nov. 28	−8° Dec. 13
Check, not cut	19.29	13.66	31.31	18.79	24.00
Sept. 1	55.60	25.58	45.51	43.71	46.08
Sept. 15	38.14	24.49	45.04	35.83	44.34
Sept. 30	26.76	17.11	36.13	29.50	31.96
Oct. 15	25.45	14.26	32.96	21.34	25.63
Oct. 30	21.69	13.09	30.30	18.99	24.78

The data show that freezing the roots of alfalfa caused liberation of more electrolytes from plants cut in September, especially September 1 and 15, than from any other treatment. The narrowing of the

differences in the data obtained from trials on October 30 and November 14 was due to the temperature to which the roots were exposed. This serves to emphasize the necessity of carefulness in the handling

TABLE 6.—*Electrical conductivity measurement of the total free extractable salts liberated by boiling the roots of alfalfa plants cut in the late summer and early fall of 1935.*

Date of cutting, 1935	Total salts extracted by boiling, Mhos ($\times 10^{-6}$) per gram of water				
	Oct. 17	Oct. 30	Nov 14	Nov 28	Dec. 13
Check, not cut	57.13	53.17	44.62	38.53	37.68
Sept. 1	57.04	56.79	52.70	43.33	39.89
Sept 15	57.70	57.63	47.58	41.94	39.40
Sept 30.	59.67	51.63	45.35	38.49	37.59
Oct 15	56.12	54.29	45.75	37.84	38.82
Oct. 30	55.82	56.35	46.42	37.82	40.86

of plant tissue used in electrical conductivity trials The plants were too far advanced in hardening on October 30 to be injured materially by exposure to a temperature of −3° C for 6 hours. A temperature of −8° C with an exposure of 5½ hours on November 14 was too extreme and all samples were severely injured. In both cases, although the ranking was not markedly changed, the differences were reduced.

Killing the roots by boiling causes increased permeability of the plasma membrane and allows exosmosis of the free extractable salts which the cells contain Table 6 shows the total salts per gram of moisture which was extracted from the alfalfa root by boiling. Little variation was apparent on any date of trial. A greater total amount of salts was extracted from the roots of plants cut in September, due to the higher moisture content, but actually, no material difference existed in the concentrations of salts per gram of moisture.

EFFECT OF LATE CUTTING UPON YIELD

The real significance of the influence of the cutting management is its effect on yield. Two cuttings of alfalfa were harvested in the summers of 1935 and 1936 from the plats cut in the late summer or early fall of the preceding seasons Yield determinations were made on the basis of cured hay containing 15% moisture. They are reported in Table 7.

The yield data for 1935 show a significant reduction in the first hay crop from the plats cut September 15 and September 30, 1934, while in 1936 first cutting yields were significantly reduced on the plats cut the previous September 1 and 15. The difference in vigor of the plants was much more apparent 2 weeks prior to removal of the first cutting than it was at harvest time and yield differences were not material in second cuttings, although the stand differences due to winter injury still prevailed.

Yield differences were due to two factors, more winterkilling with loss of stand, and the lesser vigor of the alfalfa cut at most

TABLE 7 — *The influence of late summer and early fall cutting of alfalfa on the yield of hay the following season.*

Treatment previous fall	Yield of hay, tons per acre at 15% moisture					
	First cutting		Second cutting		Total	
	1935	1936	1935	1936	1935	1936
Check, no fall cutting	2.42	1.87	1.47	0.31	3.89	2.18
Cut Sept 1	2.32	1.39*	1.52	0.28	3.84	1.67*
Cut Sept 15	2.00*	1.48*	1.38	0.26	3.38*	1.74*
Cut Sept 30	1.97*	1.66	1.27	0.30	3.24*	1.96
Cut Oct 15	2.19	1.65	1.29	0.26	3.48	1.91
Cut Oct 31	2.24	1.97	1.36	0.32	3.60	2.29

*Yield significantly lower than that of check.

critical September dates. A part of the winterkilling of the 1936 crop was due to heaving. It was estimated that at least 25% of the plants in the plats cut September 1 and September 15, 1935, heaved in the following spring. Most of the heaving injury occurred during the first week of April.

As has previously been noted, the greatest injury to the 1935 crop resulted from clippings made September 15 and 30, 1934. The 1936 crop as indicated by crown bud development, electrical conductivity tests, and finally by yield, received its greatest damage from cuttings made September 1 and 15, 1935, with little or no damage from cuttings made September 30 and later. This difference appears to be due to the much earlier occurrence and greater severity of frosts in October, 1935, than was the case in 1934. Frosts occuring each night from October 4 to 8 completely killed the new growth from September 1 cuttings in 1935, acting similarly to another cutting, whereas in 1934 the plants cut September 1 had an additional 10 days to 2 weeks to recover from the effects of the cutting before freezing. In fact, these plants did not show serious frost injury any time throughout October.

The question may be raised as to whether or not the September cuttings were not materially influenced by the earliness in stage of cutting as related to the time of removal of the second crop cut previously. Such early cutting influence is probable as a contributor to the injury. However, plats from which a third cutting was removed September 1, 1934, were not seriously injured by this treatment because a favorable fall gave them ample time for recovery. Alfalfa cut September 1, 1935, was injured when heavy freezing in early October did not permit of a long enough growing season to enable plants to recover from this cutting. Plats cut in October have not shown serious yield reductions, probably because no new growth was initiated subsequent to cutting. Injury to alfalfa due to fall cutting may also be influenced by the time of removal of the second crop. These were cut in early August, a normal date for this section of Michigan, so the trials have a direct bearing on present farm practice.

The matter of having a top growth for mechanical protection and to hold snow appears to have been of relatively little importance as regards winter injury to these alfalfa plats as evinced by the crown bud development and subsequent vigor of growth and yield of the plats cut in late October.

SUMMARY

A study of the effect of late summer and early fall cutting on the alfalfa plant is reported. Data were collected from plats of alfalfa cut on September 1, 15, and 30, and October 15 and 30, 1934, and from a similar set of plats in 1935. The effect of late cutting upon crown bud formation, stem production, forage production, percentage of moisture, percentage of dry matter, rate of respiration, and rate of hardening were determined. The data show that:

1. Alfalfa plants cut in September developed fewer crown buds per plant than those which were not cut or were cut during October
2. When active growth was resumed in the spring, fewer stems were produced by the plants cut the previous September.
3. The yield of the first crop of forage the following year was significantly less from alfalfa plants cut in September than those not cut or those cut in October. No consistent differences in the factors studied occurred in the second crop, but the total yield of hay for the season from the plants cut on critical September dates was significantly less than that of plants which were not cut on these dates.
4. Roots of alfalfa plants cut in September were lower in percentage dry matter and higher in percentage moisture than those which were not cut or which were cut in October.
5. There was no significant difference in the quantity of carbon dioxide liberated from the roots of alfalfa plants which were cut and those which were not cut
6. Electrical conductivity determinations showed that alfalfa plants cut in September were more susceptible to winter injury. This was further borne out by observations made in the spring which showed severe winter killing and heaving of plants cut the previous September.
7. Seasonal weather conditions influenced the exact date of cutting upon which maximum injury to the alfalfa plant resulted. Alfalfa plants from which first and second cuttings had been removed at normal dates were cut during late October with little effect from this removal of top growth.
8. Although it was not the object of this paper to deal with root reserves, the lower percentage of dry matter in the roots indicated that cutting during September induced the plants to draw upon the energy reserves of the root to initiate new growth.

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EFFECT OF LUTEUS GENES ON LONGEVITY OF SEED IN MAIZE[1]

Martin G. Weiss and John B Wentz[2]

IN linkage studies with maize during the winter of 1934 35, it was found that seed of F_2 progenies which had given good 3:1 ratios of normal and $luteus_2$ seedlings the previous year were, after the year in storage, showing distinct shortages of the yellow seedlings. This led to the suspicion that possibly the $luteus_2$ gene in the homozygous condition had affected the viability of the seed. The purpose of the study reported in this paper was to determine the effect of each of the several luteus genes in maize on the longevity of the seed and on the rate of germination and growth of the seedlings.

MATERIALS

Eight genes have been reported which produce the luteus (yellow seedling) character in maize. The authors were able to obtain seed adapted to this problem of all of the luteus stocks excepting $luteus_3$ and $luteus_7$.[3]

All of the luteus genes behave as single genetic recessives. $Luteus_1$, however, does not express itself phenotypically unless it occurs in the double recessive condition with a white, virescent, or striped seedling factor.

The $luteus_1$ material used was homozygous for that gene and segregating for a white and a virescent seedling character causing 3:1 and 9:7 ratios of normal to luteus seedlings, depending upon whether the progenies were segregating for one or both of the accompanying characters.

Because of the close linkage between a gene causing small pollen and differential fertilization and the allelomorph of $luteus_8$ in the seed used, abnormally large proportions of $luteus_8$ seedlings were obtained. Comparative percentages of luteus seedlings obtained at different planting dates were consequently used as an indication of the effect of $luteus_8$ on the longevity of the homozygous $luteus_8$ seeds.

The $luteus_2$ and $luteus_4$ progenies were also segregating for $virescent_{18}$, and half of the $luteus_2$ progenies were segregating for a white seedling character. This offered an opportunity to observe any effect of the virescent and white genes on germination and vigor of seedlings.

Of the $luteus_5$ seed available, some of the progenies were segregating for an unknown virescent seedling character. In these progenies, because of the small quantity of seed, the normal and virescent seedlings were grouped together.

METHODS OF PROCEDURE

Seed from progenies segregating for luteus genes was planted in flats in the greenhouse at various intervals of time after harvest, and the percentages of normal and luteus seedlings compared with the percentages which had been obtained when seed of the same progenies was planted soon after harvest.

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[2]Formerly graduate student, Iowa State College, now Junior Geneticist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Associate Professor of Farm Crops, respectively.

[3]The $luteus_1$ seed was supplied by Dr. E. W. Lindstrom and the $luteus_5$, $luteus_6$, and $luteus_8$ seed by Dr. M. M. Rhoades.

The effect of luteus genes on the rate of germination was determined by comparing the germination rate of new and old seed which was segregating for the luteus genes. Seed, produced in both 1933 and 1934, which was segregating for each of the viability-decreasing genes, was planted in February, 1935, in sand at a uniform depth of 1 inch. The seed was considered to have germinated when the growing point of the plumule penetrated the surface of the sand. The number of days required for the germination of luteus and normal seedlings was recorded for both new and aged seed.

Apparent differences in rate of growth between the normal and luteus seedlings which germinated after the seed had aged led to an attempt to determine the significance of these differences. The criteria employed to measure seedling growth was the individual green weight of each seedling after it had been severed from the roots at the secondary root node. Kempton[4] proved that the growth rate of normal and chlorophyll-deficient maize seedlings does not differ significantly until the third leaf is produced. Any differences in growth rates of seedlings in this experiment can therefore be largely attributed to decrease of vigor of the embryo. The same seedlings upon which germination rates had been obtained were used in this experiment. The weight of each seedling was obtained 5 days after it had germinated.

RESULTS

EFFECT OF LUTEUS GENES ON LONGEVITY OF SEED

In the following tables data are presented on the germination of seed of progenies segregating for the various luteus genes which had been in storage for varying lengths of time.

Luteus$_1$.—Table 1 presents germination percentages and ratios of normal and luteus$_1$ seedlings grown from 6-year-old seed of progenies

TABLE 1.—*Progenies segregating for luteus$_1$ from seed grown in 1929 and tested in 1935.*

Pedigree	Number of seeds planted	Germination %	3:1 ratios		9:7 ratios	
			Normal	Luteus	Normal	Luteus
8366–6 ...	150	80.7	94	27	—	—
7...	300	98.0	231	63	—	—
8368–1	300	65.0	144	51	—	—
2 ..	300	90.0	217	53	—	—
8369–1 .	100	98.0	—	—	52	46
3 ..	350	78.6	206	69	—	—
4...	350	98.0	—	—	186	157
8 ..	175	98.3	—	—	97	75
15...	325	96.3	242	71	—	—
8370–31...	300	92.7	218	60	—	—
8371–6 ..	250	98.4	188	58	—	—
13 ..	200	90.0	135	45	—	—
21 .	250	81.2	147	56	—	—
Total.....	3,350	89.2	1,822	553	335	278
Expected .			1,781.25	593.75	344.81	268.18

[4]KEMPTON, J. H. The rate of growth of green and albino maize seedlings. Jour. Agr. Res., 29:311–312. 1925.

which were homozygous for the luteus$_1$ gene and segregating for a white and virescent gene causing 3:1 and 9:7 ratios. Although there is a wide range of germination percentages in the different progenies, there is no evidence that the presence of the luteus$_1$ gene in the homozygous condition had any effect on longevity. There is a shortage of luteus seedlings in the total of the 3:1 ratios but a slight excess in the 9:7 ratios. In comparing the observed with the calculated ratios, the values of P were .06 and .57, respectively.

The data show quite conclusively that the luteus$_1$ gene had no effect on longevity of seed, within the time limits of this experiment.

Luteus$_2$. The progenies segregating for luteus$_2$ were known to be segregating for virescent$_{18}$ and when planted half of the progenies were found to be segregating for an unknown white seedling character. As the white character inhibits the development of luteus$_2$, the progenies were divided into two groups according to whether they were or were not segregating for albinos.

Table 2 presents the data from the progenies which were segregating for luteus$_2$ and virescent$_{18}$. The seed from which these progenies were grown was produced in 1933 and the seedling progenies were grown in the greenhouse in the winters of 1933-34, 1934-35, and 1935-36. In all cases record was kept of the number of seeds planted so that the percentage of non-germinating or dead seed could be determined. For convenience in making comparisons, the totals in Table 2 were converted to percentages of seed planted and are presented in Table 3 along with the percentage of dead seed.

Table 3 shows a sharp decline in luteus seedlings with time of storage, while the percentages of normal and virescent seedlings remained constant. The percentage of luteus seedlings dropped from 23.6 in the winter of 1933-34 to 1.3 in the winter of 1935-36, and the percentage of dead seeds rose proportionately. The sum of the percentages of dead (non-germinating)seeds and luteus seedlings in each of the three plantings was 26.4, 26.3, and 27.0, respectively, indicating that the increase in the number of non-germinating seeds was due to poor germination of the luteus seeds.

Table 4 contains data obtained from progenies segregating for the albino character in addition to luteus$_2$ and virescent$_{18}$. In Table 5 the totals from Table 4 are converted to percentages and the percentages of dead seed are included. These two tables exhibit the same sharp decline in luteus seedlings as was shown in Tables 2 and 3. There was also a decrease in the percentages of albino seedlings, but this may be due to the fact that some of the albino seeds were homozygous for the luteus$_2$ gene. Grouping normal and virescent seedlings together, a 9:3:4 ratio of normal-virescent, luteus, and albino seedlings should be obtained if the characters are independently inherited. The observed numbers, when the seed was planted soon after harvest, approach closely this theoretical ratio, the value of P being .15. Assuming independent inheritance, one-fourth of the albino seedlings were homozygous for the luteus$_2$ gene. If the viability of these double recessive seeds is affected similarly to the seeds recessive for luteus$_2$ only, the percentage of albinos should drop from 24.5 in the first planting to approximately 18 in

Pedigree	Planted during winter of 1933–1934: Seeds planted	1933–1934: Seeds germinated: Normal	1933–1934: Virescent	1933–1934: Luteus	1934–1935: Seeds planted	1934–1935: Seeds germinated: Normal	1934–1935: Virescent	1934–1935: Luteus	1935–1936: Seeds planted	1935–1936: Seeds germinated: Normal	1935–1936: Virescent	1935–1936: Luteus
864–1	50	24	12	11	100	47	20	8	100	59	26	2
2	50	23	13	14	100	47	34	10	100	58	20	4
6	50	25	13	10	100	50	19	5	100	53	17	—
9	50	26	12	12	100	41	23	11	100	63	12	—
12	50	27	13	9	100	65	20	6	100	55	15	—
14	50	27	11	12	100	53	22	3	100	52	22	1
15	50	22	14	12	100	42	33	6	100	53	22	1
22	50	23	16	10	100	35	34	3	100	50	25	—
24	50	13	23	14	100	41	35	10	100	56	16	4
26	50	28	12	9	100	58	16	5	100	58	23	—
27	50	19	15	16	100	44	34	8	100	47	25	5
30	50	28	10	9	100	61	15	3	100	50	18	1
39	50	25	12	12	—	—	—	—	100	49	26	4
40	50	23	13	14	100	44	35	12	100	50	19	2
51	50	24	13	12	100	58	22	2	100	57	19	—
53	50	22	17	11	100	51	21	3	100	42	23	—
54	50	13	14	22	100	37	34	13	100	49	19	—
56	50	23	18	8	100	45	31	11	100	42	24	—
866–1	250	131	46	70	250	138	36	—				
3	250	134	45	60	138	67	24	8				
10	250	139	57	52	204	124	34	13				
19	250	134	47	60	254	160	32	36				
25	250	130	48	58	100	52	15	3				
26	250	143	46	51	150	84	24	8				
35	250	138	49	58	64	40	10	2				
36	150	85	25	38	125	75	21	7				
37	250	134	50	62	100	59	21	—				
43	250	131	44	69	74	49	10	4				
47	150	82	24	40	100	60	18	5				
52	250	148	43	45	100	47	20	3				
55	250	144	46	52	100	46	16	3				
Total.....	3,950	2,088	821	932	3,459	1,820	729	211	1,800	943	371	24

TABLE 3.—*Totals of various classes in Table 2 converted into percentages of total number of seeds planted.*

Class	Planted during winter of					
	1933-1934		1934-1935		1935-1936	
	Total	Per cent	Total	Per cent	Total	Per cent
Dead	109	2.8	699	20.2	462	25.7
Normal	2,088	52.9	1,820	52.6	943	52.4
Virescent	821	20.8	729	21.1	371	20.6
Luteus	932	23.6	211	6.1	24	1.3

the last planting. The actual percentage of albinos in the last planting was 16.5. This is convincing evidence that the longevity of seeds homozygous for luteus$_2$ was greatly decreased.

Luteus$_4$.—Tables 6 and 7 present data on luteus$_4$. The progenies in Table 6 were segregating for virescent$_{18}$ as well as luteus$_4$ and fairly good 9:3:4 ratios are exhibited in the seedlings grown in 1933-34. From the totals in Table 7 it is seen that there were 23.6% of luteus seedlings in the 1933-34 test, but that this percentage dropped to 7.3 the following year and to 1.0 the next year. For the same 3 years the percentages of normal and virescent seedlings remained practically constant.

Luteus$_4$ seems to have approximately the same effect on longevity of seed as luteus$_2$. By comparing Tables 3 and 7, where equally aged seed of luteus$_2$ and luteus$_4$ was used, it is observed that the percentages of luteus seedlings are strikingly similar in each of the three years.

Luteus$_5$.—The luteus$_5$ seed that was available had been grown in 1932 and was segregating for an unknown virescent seedling character. Due to the small numbers, the normal and virescent seedlings were grouped together and designated as normal. When this was done the numbers of normal and luteus seedlings approached very closely a 3:1 ratio. Evidently the luteus$_5$ gene had had no effect on the longevity of the seed (Table 8).

Lutesu$_6$.—The luteus$_6$ seed had been grown in 1932 and, when tested in 1935, gave good 3:1 ratios of normal and luteus seedlings. Apparently the seeds that were homozygous for the luteus$_6$ gene maintained their viability as well as those producing normal seedlings. The data are presented in Table 9.

Luteus$_8$.—Dr. M. M. Rhoades who supplied the luteus$_8$ seed also contributed ratios of normal and luteus seedlings obtained from the progenies during the winter of 1933-34 soon after the seed was harvested. Table 10 contains the data contributed by Dr. Rhoades, together with data obtained by the authors in the fall of 1935. The ratios are abnormal because of a close linkage between luteus$_8$ and a gene causing small pollen grains resulting in differential fertilization. It will be observed, however, that the percentages of luteus seedlings

Pedigree	Planted during winter of														
	1933–1934					1934–1935					1935–1936				
	Seeds planted	Seeds germinated				Seeds planted	Seeds germinated				Seeds planted	Seeds germinated			
		Normal	Virescent	Luteus	Albino		Normal	Virescent	Luteus	Albino		Normal	Virescent	Luteus	Albino
864–3	50	18	8	10	13	100	34	23	12	21	100	51	17	1	11
7	50	17	9	12	12	100	39	19	7	23	100	27	26	4	24
11	50	16	7	7	19	100	33	28	5	22	100	44	13	—	13
16	50	17	7	11	7	100	28	16	4	22	100	38	14	1	17
17	50	14	19	7	9	100	34	20	17	22	100	48	18	1	11
19	50	15	9	11	15	100	34	24	2	16	100	38	11	—	20
31	50	18	7	9	13	100	29	21	5	23	100	38	15	—	19
33	50	18	10	11	10	100	30	20	8	15	100	55	13	1	8
44	50	26	3	11	7						60	22	11	—	14
45	50	19	8	12	10						100	35	12	1	25
47	50	15	12	12	9	100	31	24	11	21	100	41	10	1	16
48	50	18	10	6	15	100	41	13	2	19					
49	50	16	8	9	16	100	41	20	5	20	100	40	14	—	17
58	50	19	6	13	12	100	35	20	5	20	100	39	18	—	11
65	50	17	10	10	11	100	36	21	2	16	100	28	21	1	18
866–6	50	17	5	7	18	122	55	14	3	28					
7	250	108	39	34	60	180	87	21	5	35					
9	250	97	45	37	61	106	45	15	4	21					
20	250	113	32	39	55	50	28	3	1	6					
24	245	94	43	40	64	152	59	19	8	31					
28	250	101	30	38	66	150	54	20	10	34					
33	250	108	46	34	62	134	53	15	7	24					
44	250	106	30	49	58	50	26	9	—	6					
46	250	96	41	37	61	225	93	26	12	47					
48	250	98	37	35	51	200	72	20	—	35					
53	150	57	22	23	45	25	12	5		3					
56	250	103	30	50	60	150	62	17	2	21					
57	150	51	14	27	42	100	37	10	5	15					
Total	3.595	1,412	547	601	881	2,944	1,128	463	142	566	1,360	544	213	11	224

TABLE 5.—*Totals of various classes in Table 4 converted into percentages of total number of seeds planted.*

Class	Planted during winter of					
	1933-1934		1934-1935		1935-1936	
	Total	Per cent	Total	Per cent	Total	Per cent
Dead	154	4.3	645	21 9	368	27.1
Normal	1,412	39.3	1,128	38 3	544	40 0
Virescent	547	15.2	463	15 7	213	15.7
Luteus	601	16.7	142	4.8	11	.8
Albino	881	24.5	566	19.2	224	16.5

were practically the same in the 1933-34 and 1935 tests, indicating that $luteus_8$ does not effect the viability of seed within this period of time.

RATE OF GERMINATION OF $LUTEUS_2$ AND $LUTEUS_4$ SEED

Obvious differences in the rate of germination of luteus and normal seedlings from aged seed led to an effort to determine the extent of these differences. Stocks of seed segregating for $luteus_2$ and $luteus_4$ which had been produced in the summers of 1933 and 1934 were planted under uniform conditions The numbers and percentages of seedlings pushing through the sand each day are recorded for the various segregating classes of both ages of seed in Table 11.

The data in Table 11 show that $luteus_2$ and $luteus_4$ seed produced the previous summer germinated as rapidly as normal seed, but luteus seed which was 1 year old germinated much more slowly. The peak of the germination of the aged luteus seed came 1 day after the peak of the germination of normal seed and new luteus seed. The aged luteus seed also continued to germinate for several days after the germination of normal and new luteus seed had ceased. It is also interesting to note that there is no evidence of any effect of the virescent and albino characters on the rate of germination.

RATE OF GROWTH OF $LUTEUS_2$ AND $LUTEUS_4$ SEEDLINGS

Observations revealed that $luteus_2$ and $luteus_4$ seedlings from aged seed grew much more slowly than did normal seedlings or luteus seedlings from new seed. Seed, produced during the summers of 1933 and 1934, which was segregating for $luteus_2$ and $luteus_4$ was planted in sand in March, 1935. Individual weights were taken on luteus and normal seedlings 5 days after they emerged from the sand. The seedlings were all weighed the same number of days after they had emerged to correct for differential germination rates. The means of the weights of normal and $luteus_2$ seedlings are presented in Table 12. Similar data for $luteus_4$ are presented in Table 13. In both cases the luteus seedlings from 1934 seed did not differ significantly in weight from the normal seedlings from 1934 seed, but the differences

TABLE 6.—*Progenies segregating for luteus$_4$ and virescent$_{18}$ from seed grown in 1933*

Pedigree	Planted during winter of											
	1933-1934				1934-1935				1935-1936			
	Seeds planted	Seeds germinated			Seeds planted	Seeds germinated			Seeds planted	Seeds germinated		
		Normal	Virescent	Luteus		Normal	Virescent	Luteus		Normal	Virescent	Luteus
871–4	200	111	50	35	100	54	16	3	49	25	10	—
6	250	139	46	61	100	54	21	7	25	10	8	—
7	150	88	21	41	100	59	24	8	25	15	4	—
8	250	137	50	62	100	60	16	5	99	58	14	—
9	250	140	52	55	100	57	16	16	150	84	29	1
12	250	160	35	55	100	60	11	6	50	30	9	1
13	153	96	23	32	159	90	26	5	57	33	10	—
15	250	141	55	53	200	122	26	9	75	50	11	—
19	250	139	40	65	100	70	17	8	125	73	15	3
20	200	110	37	47	98	60	14	3	50	28	8	—
23	200	93	43	57	100	57	19	4	75	42	15	—
24	200	109	31	56	200	109	27	9	150	84	26	—
25	200	116	45	38	200	121	34	17	50	37	7	—
31	200	111	31	51	100	54	17	17	100	45	22	6
32	100	56	14	25	89	52	18	4				
33	250	132	37	61	77	30	15	7				
35	200	117	36	46	97	41	21	15				
37	200	118	33	47	56	31	13	9				
Total. . .	3,753	2,113	679	887	2,076	1,172	351	152	1,080	614	188	11

TABLE 7.—*Totals of various classes in Table 6 converted into percentages of total number of seeds planted*

Class	Planted during winter of					
	1933-1934		1934-1935		1935-1936	
	Total	Per cent	Total	Per cent	Total	Per cent
Dead	74	2.0	401	19.3	267	24.7
Normal	2,113	56.3	1,172	56.5	614	56.9
Virescent	679	18.1	351	16.9	188	17.4
Luteus	887	23.6	152	7.3	11	1.0

TABLE 8.—*Progenies segregating for luteus$_5$ from seed grown in 1932 and tested in 1935*

Pedigree	Normal	Luteus
2357-1	49	15
3	72	20
5	46	12
6	78	29
7	28	11
Total	273	87
Expected	270	90

TABLE 9.—*Progenies segregating for luteus$_6$ from seed grown in 1932 and tested in 1935*

Pedigree	Normal	Luteus
2359-2	104	23
4	133	40
7	69	20
8	71	28
Total	377	111
Expected	366	122

TABLE 10.—*Progenies segregating for luteus$_8$ from seed grown in 1933.*

Pedigree	Planted winter 1933-34			Planted fall 1935		
	Normal	Luteus	% luteus	Normal	Luteus	% luteus
2482-1	50	71	58.7	14	14	50.0
12	37	60	62.0	29	53	64.6
15	54	63	53.8	76	107	58.5
19	35	70	66.7	25	51	67.1
Total	176	264	60.0	144	225	61.0

TABLE 11.—*Numbers and percentages of seeds germinating each day.*

Class	Date and rate of germination												Total seeds germinated
	Mar. 9	%	Mar. 10	%	Mar. 11	%	Mar. 12	%	Mar. 13	%	Mar. 14	%	
					Luteus₂, 1933 Seed								
Normal	19	9.6	146	73.7	31	15.7	2	1.0	–	—	–	—	198
Virescent	5	10.2	36	73.5	7	14.3	1	2.0	–	—	–	—	49
Albino	1	3.0	29	87.9	3	9.1	–	—	–	—	–	—	33
Luteus	—	—	3	17.7	8	47.1	3	17.6	2	11.8	1	5.9	17
					Luteus₂, 1934 Seed								
Normal	13	5.4	172	71.1	53	21.9	1	0.4	2	0.8	1	0.4	242
Virescent	1	5.0	13	65.0	6	30.0	–	—	–	—	–	—	20
Albino	1	4.5	18	81.8	3	13.6	–	—	–	—	–	—	22
Luteus	4	4.5	64	72.7	17	19.3	3	3.4	–	—	–	—	88
					Luteus₄, 1933 Seed								
Normal	4	1.8	154	70.3	59	26.9	2	0.9	–	—	–	—	219
Virescent	3	5.0	51	85.0	6	10.0		—	–	—	–	—	60
Albino	1	4.6	15	68.2	5	22.7	1	4.6	–	—	–	—	22
Luteus	—	—	3	15.8	11	57.9	2	10.5	2	10.5	1	5.3	19
					Luteus₄, 1934 seed[1]								
Normal	7	3.0	136	57.6	88	37.3	1	0.4	3	1.3	1	0.4	236
Luteus	2	3.4	32	54.2	23	39.0	2	3.4	–	—	–	—	59

in weight of luteus seedlings from 1933 seed and normal seedlings from seed of the same year were significant.

TABLE 12.—*Means of weights in grams of seedlings grown in March 1935 from seed segregating for luteus$_2$.*

Pedigree	Normal		Luteus		Difference	"t" value
	Number of seedlings	Mean weight	Number of seedlings	Mean weight		
		1934 Seed				
906-1	46	.581	17	.566	.015	—
907-1	72	.454	25	.466	-.012	—
907-1.	65	.460	29	.422	.038	—
907 3	56	.484	13	.499	-.015	—
Mean difference					.0065	.04
		1933 Seed				
866 7	56	.431	5	271	.160	—
866-19	64	.541	12	324	.217	—
866-26	47	.562	6	313	249	—
866 46	36	721	6	.281	.440	—
Mean difference					.2665	3.86*

*Significant

TABLE 13.—*Means of weights in grams of seedlings grown in March 1935 from seed segregating for luteus$_4$*

Pedigree	Number of seedlings	Mean weight	Number of seedlings	Mean weight	Difference	"t" value
		1934 Seed				
916-3	57	.520	19	.461	.059	—
917-2	89	.718	22	.695	023	—
918 1	35	.481	15	.518	-.037	—
918 2	52	.648	18	.682	-.034	—
Mean difference					.00275	.01
		1933 Seed				
871-9	58	.646	11	.403	.243	—
871-24	54	.566	9	.215	.351	—
871-25	56	.548	12	.313	.235	—
871-35, 37	46	.424	6	.280	.144	—
Mean difference					.24325	5.79**

**Highly significant.

Luteus$_2$ and luteus$_4$ seedlings from aged seed were greatly reduced in vigor and grew slower than normal seedlings or luteus seedlings from new seed.

DISCUSSION

Perhaps the most interesting contribution in this paper is the evidence of the rapid decline of viability of seed homozygous for $luteus_2$ and $luteus_4$ genes. Of further interest is the fact that both of these genes are located on chromosome 10 of maize, while two other luteus genes, $luteus_1$ and $luteus_8$, also located on this chromosome, do not affect the viability of seed.

More complete data could be obtained on the rapidity of the devitalizing action of $luteus_2$ and $luteus_4$ by obtaining progenies with large populations segregating for these genes and planting some of the seed at regular intervals to determine the curve described by the descent of viability

Considerable variation is noticed between progenies as to the rate of the decline in viability of the seeds homozygous for $luteus_2$ and $luteus_4$ For instance, in pedigree 866 which was segregating for $luteus_2$, after 1 year of dormancy, progeny 1 gave no yellow seedlings out of 250 seeds planted, while progeny 19 showed over 14% yellow seedlings out of 254 seeds planted. Both of these progenies were segregating approximately 25% yellow seedlings the previous year All progenies, however, did show significant decreases

The effect of the $luteus_2$ and $luteus_4$ genes on the rate of germination and vigor of homozygous luteus seedlings indicates that the lowering of the viability is a gradual process the end point of which is the death of the embryo It would be of interest to both the geneticist and the physiologist to know the nature of the action of the luteus genes which causes the loss of viability of the seed The genes must bring about some effect in the seed, possibly chemical or enzymatic, which causes the low germination There is some evidence in this paper, however, from the progenies segregating for albinos, that the lack of viability is not associated with the visible effect of the genes on the pigment content. The authors made some simple anatomical and chemical studies of the seeds, but these studies revealed no differences in the luteus and normal seeds It is possible that more exhaustive studies would find some differences and that such findings would contribute something of value to our knowledge of viability and longevity of seeds

There is a possibility that the $luteus_2$ and $luteus_4$ genes do not cause the decrease in viability, but that each of these two genes is closely linked with a gene which causes the loss in viability If this were the case, however, one could expect some crossovers which would cause some of the progenies to give normal ratios of luteus seedlings from aged seed. There was considerable variation in individual progenies, but none of the progenies from aged seed gave normal proportions of luteus seedlings.

SUMMARY

Two genes in maize were found to be closely associated with longevity of seed. Evidence was obtained showing that the viability of seeds homozygous for the $luteus_2$ and $luteus_4$ genes was definitely decreased during dormancy. Progenies segregating approximately

25% of luteus seedlings soon after the seed was harvested dropped to approximately 1% of luteus seedlings after 2 years of dormancy

No decrease in viability of seeds homozygous for $luteus_1$, $luteus_5$, $luteus_6$, or $luteus_8$ was observed

Seeds homozygous for the $luteus_2$ and $luteus_4$ genes not only were lowered in percentage of germination, but seedlings therefrom were greatly reduced in vigor This was proved by comparison of germination rates of new and 1-year-old seed segregating for the luteus genes and by comparing the growth rates of normal and luteus seedlings in new and old seed Using seedling weights as a criteria of measurement, there were no significant differences between the rate of growth of normal and luteus seedlings in new seed, but there were significant differences when old seed was used.

LONGEVITY OF LEGUME BACTERIA (RHIZOBIUM) IN WATER[1]

WM. A. ALBRECHT AND T. M. McCALLA[2]

THE length of time cultures of legume bacteria will remain viable under various storage conditions is a matter of no small importance in laboratory practice and especially in the commercial production of cultures for inoculating legume seeds. The longevity of legume bacteria (Rhizobium) in the soil has been reported (1, 4)[3] with the suggestion that these bacteria maintain themselves in the absence of the host for a relatively long time. They do so under drastic conditions, most pronounced of which is a significantly low moisture supply. The present study was undertaken as a test of their ability to live in the presence of excessive moisture and low aeration. These conditions were provided in stoppered bottles of ordinary tap water, distilled water, and an aqueous solution of very low nutrient content. This nutrient supply was limited to calcium which has been associated with inoculating ability and longevity in the soil (2, 3, 4, 5).

EXPERIMENTAL

The soybean (*Rhizobium japonicum*) and cowpea (*Rhizobium* ?) bacterial cultures were grown as the laboratory stock cultures on the customary sucrose-mineral medium until in a very active stage. They were washed from the surface of the agar and then suspended in the respective sterile aqueous solutions. These solutions included (a) distilled water only, (b) distilled water with calcium chloride in the proportions of 1:1,250 and 1:1,500, and (c) ordinary tap water.

The tap water was drawn from the deep wells of the University, often supplemented from the city supply from still deeper wells. Both sources offer water of decided hardness and high salt content of the alkalis and alkaline earths.[4]

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 482. Received for publication October 22, 1936.

[2]Professor of Soils and Graduate Student in Soils, respectively. Acknowledgment is made of the help of R. W. Scanlan in the earlier part of this study.

[3]Figures in parenthesis refer to "Literature Cited", p. 78.

[4]Boiler water analyses give the following composition for water from these sources:

Constituent	Quantities in p.p.m.	
	University wells	City wells
Calcium	58.0	79.0
Magnesium	28.8	27.0
Sodium	22.7	34.0
Chlorine	22.3	37.0
Sulfate	47.2	34.0
Bicarbonate	—	355.0
Dissolved oxygen	—	6.0
Silicon	—	8.0
Iron and aluminum	—	5.0
pH	—	8.3
Total solids	365.0	411.0

The exact source of the tap water on the date of each trial was not taken into account, though considered and used because of its relatively high hardness to soap (276 total as calcium carbonate), or high content of calcium, and its alkaline reaction. The distilled water was produced by condensing scrubbed steam and filtering through charcoal with a relatively high grade of distilled water as the result. This was also used in making the calcium chloride solutions.

The bottles were filled to about three-fourths capacity, tightly stoppered, and stored away in the dark of a laboratory cabinet for 42 months (1925–29) in the first test using the soybean organism and for 9 months (1935–36) in the second test using the cowpea bacteria.

In both trials, the stored cultures were tested by using definite quantities on sterile seeds in sand cultures to test their possibility of nodule production. In the first trial with soybean organisms, sterile sand both with and without the addition of a nutrient solution was employed. Check trials on the method were included and all possible chances for contamination excluded. No plate counts were made in the first test, but plated loop dilution transfers were studied for the lens-shaped, imbedded colonies, and the clear, raised, gelatinous, surface colonies so characteristic of the legume bacteria. In the second trial, where cowpea bacteria were used, plate counts were carefully made in addition to the nodulation tests on plants in sand cultures. The data on these plate counts and on the nodule production on the host plants for both trials are assembled in Tables 1 and 2.

TABLE 1.—*Nodule production by soybean bacteria after storage in water for 42 months.*

Suspension medium	pH of suspension 1925	pH of suspension 1929	Inocula per seed, cc	1st trial: No. of plants used	1st trial: Nodules per plant	2nd trial: No. of plants used	2nd trial: Nodules per plant
			Oct. 1925 to April-May 1929*				
Tap water	7.1	8.3	5.00 1.00 0.01	25	0	15	0
Calcium chloride 1:1,250	7.1	7.6	5.00 1.00 0.01	25	0	15	0
			Nov. 1925 to April-May 1929*				
Tap water	6.7	7.3	5.00 1.00 0.01	8 9 6	7 1 1.5	30	14.7
Calcium chloride, 1:1,500	6.7	7.1	5.00 1.00 0.01	25	0 0 0	30	0

*Cultures put into storage on first date; storage period terminated and test made on second date.

Both plate and nodulation tests in 1929 and 1935 show that a significant number of legume bacteria may be present after storage

TABLE 2.—*Nodule production by cowpea bacteria after storage in water for 9 months, Sept. 1935 to June 1936.*

Suspension medium	Bacteria per cc	Inocula per seed, cc	No. of plants used	Nodules per plant
Tap water	885 940	10	10	Numerous*
Calcium chloride, 1:1,250	26 12	10	10	0
Calcium chloride, 1:1,500	0 0	10	10	0
Distilled water	0 0	10	10	0

*Nodules very numerous, small, and not counted.

for a considerable time in tap water. Those in dilute solutions of calcium chloride retained their viability for 9 months in the lower concentration of this salt according to the plate count, and suggest a helpful effect of calcium salt alone in distilled water. Those which remained viable for the longer periods and in significant numbers were stored in tap water, containing other salts in addition to calcium. This combination of salts in a solution almost exclusively mineral, served as a medium to carry the micro-organisms in viable condition for a significant length of time. Only one of the two tap water trials lasting 42 months showed viable organisms after this long period of storage. The other tap water culture failed to nodulate, though on agar culture it produced growths suggesting the clear legume bacterial colonies. There is an interesting coincidence between the two tests. The 0.01 cc of inoculum in 1929 from the tap water stored November 1925 produced nine nodules on six plants, hence had 900 bacteria per cc after 3½ years. This number agrees closely with plate counts of 885 and 940 in the second test with tap water in 1935 after 9 months storage.

CONCLUSIONS

The retention of viability of the legume bacteria under such conditions as provided in these tests suggests that apprehension regarding speedy destruction of the cultures in tap water in closed containers is unwarranted and that inoculation failures by tap water transfer of cultures can scarcely be ascribed to this water treatment.

Since tap water is in reality an aqueous soil extract, these results suggest that even in such a dilute mineral solution of the soil with a consequently low oxygen content, the legume bacteria maintain themselves in host absence for a long time.

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NOTES

SPECIFIC HYBRIDIZATION, A PROBABLE METHOD FOR PRODUCING HARDIER WINTER OATS

FOR 10 years a uniform winterhardiness experiment with oat varieties and strains has been conducted cooperatively by the U. S. Dept of Agriculture and the agricultural experiment stations of 13 states. Seedings at 34 points have resulted in the accumulation of data for 175 crop years Among the 40 varieties and strains grown for one or more seasons, 12 were included in nearly all tests on all stations. These 12 include representative strains of all distinct winter oat varietal types grown in the United States

Data obtained from these experiments (Table 1) are especially interesting to oat breeders not only because they indicate which strains are most hardy under differing conditions of soil and climate, but because of their value in planning and developing future breeding projects for the production of hardier oats.

TABLE 1 —*Average data obtained for periods of 2 years and for 10 years on the percentages of winter survival of certain oat strains included in the cooperative uniform winterhardiness experiment* *

Variety or selection	C I. No	2-year average†	Percentage of Turf	10-year average‡	Percentage of Turf
Winter Turf	3,296	65 0	100.0	64.7	100.0
Hairy Culberson	2,505	69 2	106.5	70.5	109.0
Bicknell	3,218	69 0	106.2	69 3	107.1
Culberson	273	67 0	103.1	68 4	105.7
Fulghum (winter type)	2,499	67 5	103.9	66 7	103.1
Custis	2,041	64.0	98 5	65.3	100.9
Tech	947	63.9	98 3	65.0	100.5
Appler (Red Rustproof)	1,815	55.9	86 0	64.2	99.2
Hastings Hundred Bushel (Red Rustproof)	2,462	57.1	87.8	60.2	93.6
Tennessee Sel. 090	3,175	73.7	113.4	—	—
Markton × Red Rustproof	3,178	63.8	98.2	—	—
Markton × Red Rustproof	3,179	62.1	95.5	—	—

*Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the agricultural experiment stations of Oregon, New Jersey, Virginia, North Carolina, South Carolina, Georgia, Tennessee, Mississippi, Arkansas, Louisiana, Missouri, Oklahoma, and Texas.

†Grown for a total of 45 station years for which differential data are available for 37 station years.

‡Grown for a total of 175 station years for which differential data are available for 138 station years.

Prior to conducting these experiments, strains of Winter Turf (Gray Winter, Virginia Gray, etc.) were considered our most winter-hardy varieties. Data now available indicate that several others out-rank Turf in hardiness. The varieties grown in all years that have

exceeded Winter Turf in hardiness are Hairy Culberson, Bicknell, Culberson, Fulghum (winter type) (C. I. 2499), Custis, and Tech. The superiority of the last two is slight. Among strains grown for a period shorter than 10 years, Tennessee Selection No. 090 ranks first.

Although the discovery that certain oat strains exceeded Winter Turf in hardiness is noteworthy, the nature and similarity of origin of these hardier strains is of greater interest, as all trace their ancestry more or less directly to Red Rustproof or some similar *Avena byzantina* variety, yet all have characters suggestive of *A. sativa.* No botanical description of these more hardy oats is attempted at this time, but the origin of each is briefly outlined.

Hairy Culberson was originated by T. R. Stanton at the Arlington Experiment Farm, Arlington, Va., as a reselection from a strain of Culberson selected by C. W. Warburton at College Park, Md. The original Culberson from which Warburton made his selection was received in 1904 from the North Carolina Agricultural Experiment Station. It originated as a mass selection from Red Rustproof. Both Culberson and Hairy Culberson differ widely from Red Rustproof, yet off-type individuals are observed in fields of unselected Red Rustproof that resemble Culberson. Consequently, Culberson oats, classified as belonging to *A. sativa,* are considered as having arisen from and as carrying some genes derived from Red Rustproof.

The origin of Bicknell is strikingly similar to that of Culberson. This strain of the variety originated as a selection made by T. R. Stanton at the Arlington Experiment Farm from a variety received in 1902 from F. W. Bicknell, then U. S. Consul to Buenos Aires, Argentina. The name "Argentine" was applied to this introduction by Warburton who considered it as representative of the Culberson type. He later named it Bicknell. As Bicknell came from South America, where oats of *Avena byzantina* are the most popular type grown, and as it closely resembles Culberson, it is believed that both varieties have a similar origin, i. e., both resulted as selections from *A. byzantina,* although classified as belonging to *A. sativa.*

Several Fulghum strains, of which C. I. 2499 is one, are the result of reselections made from Fulghum (C. I. 699) by T. R. Stanton at the Arlington Experiment Farm. Warburton received this Fulghum strain from the Alabama Agricultural Experiment Station in 1912. Fulghum resulted from a plant selection made by J. A. Fulghum, a farmer living near Augusta, Ga., from a field of Red Rustproof (Appler) oats. Tennessee selection 090 is a reselection from Fulghum (C. I. 2499) made by N. I. Hancock of the Tennessee Agricultural Experiment Station at Knoxville. This strain has been the most hardy of all Fulghum strains so far tested. Possibly it may prove the equal of Hairy Culberson in hardiness. The winter-type Fulghum strains differ rather widely from the original Fulghum oat as they have some characters suggestive of oats of the Culberson type.

Tech is a black-kerneled strain selected from Culberson by T. B. Hutcheson of the Virginia Agricultural Experiment Station and Custis resulted from a hybrid made by T. R. Stanton at the Arlington farm between Winter Turf and Aurora. Incidentally, the latter was selected from Red Rustproof by Warburton.

Records available enable us to trace all our more winterhardy oats to selections from Red Rustproof or some similar variety of *Avena byzantina*. Yet no strain typical of Red Rustproof is outstandingly cold resistant. Furthermore, the fact that so many hardy strains, classed as *A. sativa*, trace their ancestry to *A. byzantina* yet are not typical of that species, suggests that they originated either by mutation or natural species hybridization between *A. sativa* and *A. byzantina*.

Results obtained from segregates of the cross Markton×Red Rustproof are believed to be further evidence supporting the species hybrid theory. As typical Red Rustproof strains are not exceptionally hardy and as Markton is a common spring oat belonging to *Avena sativa*, this cross would not be expected to produce hardy progeny; yet two segregates from this cross apparently are more hardy than the best Red Rustproof strains. This seems evidence for believing that possibly those hardy oat varieties which trace their ancestry to Red Rustproof or to *A. byzantina* but are not typical of that variety may all have resulted from natural hybridization. Therefore, extensive hybridization of varieties of *A. byzantina* and *A. sativa* in a search for more winterhardy types seems desirable. Other species and genera should not be neglected.—F. A. COFFMAN, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

THE CROSSING PLOT FOR INCREASING INBRED CORN SEED

MAINTAINING inbreds true to type is one of the biggest problems confronting maize breeders and seedsmen today. It is easy to keep small samples pure by hand pollinating the ears to be used for seed and by roguing any off-type plants that may appear. It is almost impossible, by our present methods, to get a large quantity of an inbred as pure as the small sample.

The method commonly used in increasing inbreds has been outlined in Connecticut Circular 112. Other workers follow in general this policy which embraces the following principles:

1. Hand-pollinated seed used for foundation increase plot.
2. Foundation plot isolated as well as possible and properly rogued.
3. Seed produced in foundation plot used for second or larger increase plot.
4. Seed from second increase used in fields producing crossed corn.

In this method there are three chances for contamination, *viz.*, (1) in the original hand-pollinated seed; (2) in the foundation plot if not far enough from other corn or if any outcrossed plants are not rogued; and (3) in the second increase plot.

Is it possible to eliminate one of these steps? If so the chances for contamination are reduced by at least one-third. There are two ways we can shorten the process. One is to hand pollinate enough seed for the second increase plot, or, in other words, grow enough seed in the foundation plot for commercial crossing fields. This is possible but may not be feasible for the seedsman, because of making so many hand pollinations.

The second way will give almost the same results and will require much less hand pollination. This is by the crossing plot method. One illustration will show the difference between the two methods. Suppose a seedsman requires 5,000 pounds of Purdue 39 each year To grow this amount of Purdue 39 seed, approximately 5 acres will be needed, figuring conservatively 1,000 pounds of Purdue 39 from an acre. This 5-acre field will require about 40 pounds for seeding Approximately 400 to 500 hand-pollinated ears will be necessary to produce 40 pounds of seed. This is not an impossible task but rather laborious.

The alternative is to make better use of the seed that we hand-pollinate. Usually, the hand-pollinated seed is grown in an isolation plot, well manured and fertilized, to secure maximum production from the purest seed. But are we securing maximum production? From the pistillate flowers (that produce ears) yes From the staminate flowers (that produce pollen) no! We have in our isolation plot enough pollen to pollinate properly many times the number of plants grown. Why not grow a crossing plot of Purdue 39 using hand-pollinated seed for the pollen row only? For the seed rows use the best open-pollinated stock available. These rows will be detasseled the same as the seed parent in a commercial crossing plot One row of the pollen parent will completely pollinate four rows of the seed parent and perhaps more. By this method only one-fifth the amount of hand-pollinated seed is necessary. Thus it is possible to utilize smaller amounts of hand-pollinated seed Two pounds are sufficient for the male rows in an acre.

The practice of hand-pollinating seed for a foundation plot and then growing this by itself is comparable to a cattle breeder maintaining an expensive bull for each cow. We are not using all the good germ plasm in our hand-pollinated stock. The crossing plot method for multiplying inbred seed has the advantage that only about one-fifth of the hand pollinations is necessary. More important, however, is the fact that one of the steps in the multiplication of an inbred has been eliminated. This will considerably reduce the amount of contamination in the seed used for commercial production.

In using this method the hand pollinations necessary for next year's male row can be made in the present male row. The male row should be thoroughly rogued during the growing season and any questionable or outcross plants destroyed

At harvest time the male rows represent the best seed and can be kept separate. Seed produced in these rows will be used for the female rows the following year. Seed for the next year's male rows will come from hand-pollinated seed in this year's male row. Thus the system works automatically and will result in a better grade of seed being used in the production fields.

It is possible to throw out off-type ears from the female rows in the seed barn when using this method. Any such ears that occur can be discarded with the assurance that the tassels from such plants have already been removed. Under our present system it is of little value to discard off-type ears at harvest time when we know that such outcrossed plants have already produced their pollen and the damage is done.

Complete detasseling of the seed rows is just as essential as in the production of crossed seed. Detasseling is easily done and is thoroughly familiar to all interested in inbred seed. It should offer no serious obstacle in this program W. RALPH SINGLETON, *Connecticut Agricultural Experiment Station, New Haven, Conn.*

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NEWS ITEMS

In the absence of Dr. H. K. Hayes, temporarily on leave in China, Dr. E. G. Anderson, California Institute of Technology, will spend the coming winter as Visiting Professor in the Division of Agronomy and Plant Genetics, University of Minnesota. During his stay at Minnesota, Dr. Anderson will teach courses in advanced genetics, aid in the direction of seminars, advise graduate students, and assist with the genetics research program.

Dr. John Parker, Kansas State College, gave the principal address at the annual banquet of the Minnesota Crop Improvement Association during Farm and Home Week Dr. Parker spoke on "Science, Agriculture, and Industry—Partners in Crop Improvement".

The American Potash Institute, Inc., has announced the addition of Joe E. Walker to its staff as field agronomist in the southwestern states. Mr. Walker received his technical training at the Arkansas College of Agriculture and is well equipped with experience based upon several years of work as a county agent in Arkansas and Mississippi.

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SOIL CONSERVATION FROM THE VIEWPOINT OF SOIL PHYSICS[1]

RICHARD BRADFIELD[2]

SOIL conservation in the United States is a colossal problem; so colossal that but a few of us can see the problem as a whole. It varies widely in different sections of the country. The analysis of the situation in any section will depend in part upon the background and training of the investigator. In this symposium the problem will be discussed in turn by specialists in three different fields, a physicist, a microbiologist, and a chemist. I can tell you now what you can expect. It will be another story of the three blind men and the elephant. It has fallen to my lot to grasp the elephant's tusk. It is hard, dry, intractible, impervious, deflocculated, poorly ventilated! Such tilth! Is it any wonder crop yields are unsatisfactory? My friend, Dr. Waksman, is standing by my side. Being a microbiologist he does not touch the elephant! But he happens to catch a whiff of his breath and exclaims, "Halitosis! We must change his internal flora!" Dr. DeTurk, being a fertility specialist, is at the other end of the elephant! He examines the accumulated evidence, shakes his head and remarks, "We must change his diet. He is not getting enough nitrogen."

I am inclined to feel that you will find some truth in the diagnosis of each of us. In nature our special fields are inseparably intertwined. A healthy type of biological activity requires the proper physical environment and is necessary for the creation of such an environment. At the same time micro-organisms are an essential part of the mechanism by which the reserve supply of the necessary chemical elements is converted into soluble forms. Our analyses will I hope form separate segments which will fit together to give a consistent picture of the problem as a whole.

I shall divide my discussion into four sections, *viz.*, (1) the soils we had, (2) the soil we have, (3) the factors responsible for the change, and (4) what can we do to ensure good physical conditions in our arable soils?

[1]Contribution from the Department of Agronomy, Ohio State University, Columbus, Ohio. Also presented at the annual meeting of the Society at Washington, D. C., November 19, 1936, as part of a symposium on "The Scientific Aspects of Soil Conservation".

[2]Professor of Soils.

THE SOILS WE HAD

Few countries in the world have had within their borders natural soil resources which could compare in extent, variety, or fertility with those found in the United States at the time it was first settled by European colonists. I have often marveled at the protection given the soil by a virgin forest. The dense canopy over head protects the soil from the extreme heat of the sun and breaks the impact of driving rains. Underneath the canopy a dense layer of leaf litter forms an additional protective carpet, readily permeable to water, but at the same time cushioning the soil further against the impact of falling raindrops, and from compaction due to the footsteps of the relatively sparse animal population. Man or beast walking through a rain-drenched primeval forest would scarcely leave a trace of his passage. Let him walk across a cultivated field under the same circumstances and his tracks will be evident weeks later. The leaf litter also retards evaporation, gives further protection from temperature extremes, and thus makes conditions more favorable for the development of worms and insects within the soil. The leaves decay slowly releasing to the soil a part of the essential elements which they contain and leaving a humified residue which still further improves the physical condition of the soil Beneath the layer of leaves we find a dense fibrous mat of roots, each strand having a high tensile strength. These roots are perennial and some of them gradually force their way into the deeper horizons taking many years to reach their maximum spread and penetration. The surface roots anchor the soil in place, functioning in this respect as myriads of micro-brush dams. The deeper roots gradually absorb plant nutrients from the deeper horizons. These substances eventually find their way into the leaf litter and eventually back into the surface soil. By means of such a cycle the fertility of the surface soil was gradually enhanced. When these forest soils were first cleared and plowed, these roots absorbed a part of the stress applied to the soil during tillage processes. They were fairly resistant to decay and gave the soil a springy, spongy structure which prevented its hardening by beating rains for many years. After the roots and leaves had completely disappeared there remained in the soil a fairly liberal supply of their humified remains. But under cultivation this too has been gradually oxidized.

The most fertile section of our country was originally covered with prairie grasses. In many sections these grasses made such a vigorous growth that cattle could be lost in them. They were never overgrazed under natural conditions. The top growth was dense, from 500 to 2,000 stalks per square meter. The soil was always protected by some of this top growth except after the occasional prairie fires. It served much the same functions as the canopy and leaf litter in the forest. Most important of all from the viewpoint of soil physics was the mass of tough fibrous roots which ramified the soil so completely that few plants, even trees, could compete with them, even when the annual rainfall was adequate to support tree growth. Few people who have not had the privilege of guiding a plow through a virgin bluestem sod can fully appreciate the toughness of this mass of roots. They were so strongly interwoven that in the original breaking a

skilled plowman could cut and invert a continuous ribbon of sod across a quarter section of land, a half mile long. It was so tough that in many sections no attempt was made to tear it up and prepare a seedbed, but the crop was planted directly on the inverted sod. For a while these prairie soils retained their characteristic granular structure, a structure approaching more nearly the ideal physical state of the soil than anything that man has been able to devise on an extensive scale. Such was our heritage! Let us now consider our present status. Let us give an account of our heritage. What has our much-vaunted civilization done to our most valuable resource, the resource that we are dependent upon for our primary needs, our foods, our clothing, and a large proportion of the industrial products which we have come to regard as essential to our daily living?

In this discussion I shall confine myself to arable lands. Land that must be cultivated to supply our 130,000,000 people with the products of the soil required by our 20th century civilization. Soil conservation was not a problem when our country was covered with prairie sod or virgin forest. The only feasible way to preserve large areas of our more rolling and erosive soils is to cover them again with forests and grass I realize that to re-establish a satisfactory forest or grass cover on much of this land is a difficult problem. But this phase of the problem for the first time in our history is receiving some of the attention due it.

In a nation so abundantly blessed with soil resources it seems doubtful if we are justified in making the large expenditures necessary to preserve these soils under any system of arable agriculture. For this reason I shall pass quickly over the problem of marginal and sub-marginal lands and shall confine my remarks largely to our cultivated soils, soils that must be used to grow our annual crops, like corn, wheat, cotton, and tobacco I have wondered at times if in many of our recent soil conservation activities we are not making the same mistake that we make so often in our universities. We devote so much attention to the "problem boy" that we are forced to neglect the more gifted student. *In our national soil conservation program we must not allow our more productive arable lands to become the neglected step-child in our pedological family.*

THE SOILS WE HAVE

Our original forests have almost completely disappeared and with them their dense canopies and their protective influence on soil processes. The leaf litter, after the annual supply was cut off, was mixed with the soil and the rate of decomposition accelerated. It soon disappeared save for a small humus residue. The roots were killed but, being resistant to decay, kept the soil loose for a few years, but eventually became fragile and disintegrated and decomposed under the combined attack of micro-organisms and the physical and chemical weathering agencies, both of which were aided and accelerated by tillage operations. The larger, deeper roots of the trees lasted longer, but they too gradually decayed, their channels serving as drainage tubes temporarily, but they were gradually occupied by other roots and eventually filled by the washing in of surface soil. In the more

rolling sections the truncated soil profiles give unmistakable evidence of the loss of the more fertile surface horizons by sheet erosion even where there is no other visible evidence of the more striking forms of erosion. As a result of the destruction of these organic residues, biological activities have been reduced, the natural structural aggregates have been destroyed, and the soil particles tend gradually to assume a position of closer packing. In many cases from 25 to 30% more soil is crammed into a cubic foot than was present in the virgin soil. This has reduced porosity, especially the volume of larger pores through which water penetrated readily and through which the soil received the necessary ventilation. As a result of these changes in structure, root development is hampered, the storage capacity of the soil for water is reduced, flood hazard is increased, and the damage from frequent periodic drouths is magnified.

Over large areas of our fertile prairie region, the last vestige of virgin sod has disappeared. The granular structure so essential for maximum yields on many of these soils has largely been destroyed. This change has come with astonishing speed, I do not regard myself as an old man, but I had the experience of plowing some virgin prairie sod as a boy and I yet have a vivid recollection of the toughness of that sod. Today, only 25 years later, that farm is on the fringe of the "Dust Bowl."

FACTORS RESPONSIBLE FOR THE CHANGE

Some of the most obvious factors involved in this change, such as the removal of the protection from the weather which was afforded throughout the years by the perennial cover of either trees or grass have already been discussed. When these perennial covers were removed the natural development of structure was also interferred with. The processes involved in structure formation seem to operate effectively only in undisturbed soils where stabilizing materials can gradually accumulate at the interfaces between granules. For the most part we have substituted annual crops for perennials. Since their growing season is short the root systems of these annual crops are not so extensive and in general their tensile strength is less and they decompose more readily than those of perennial crops. As a result they are not in contact with the undisturbed soil long enough to help stabilize their structure.

In order to grow the annual crops which we find necessary for our modern life it is customary to perform certain tillage operations. Students of soil physics are agreed that these tillage operations temporarily loosen the soil and produce an effect that is referred to as good tilth. All available evidence indicates, however, that the ultimate effect of tillage is to accelerate the destruction of the granular structure which developes slowly in many undisturbed soils. Every time a tillage implement is forced through a soil countless granules are crushed as a result of the strain generated during the tillage process. As the granules are crushed the primary particles composing them are obliged to take up new positions in the soil mass. In many cases they clog the pores between the remaining granules forming an im-

pervious layer which Lowdermilk and others have found to be such an important factor in increasing runoff and erosion.

The dust which arises when tillage operations are performed on a soil too dry to be tilled, the crust and clods and cracks which develop after such soils have been drenched with water and allowed to dry, are other evidences of the same general phenomena. These changes have come about so slowly that one who has been following them from day to day has scarcely been aware of their existence If, however, you ask any farmer who cleared his farm from virgin forests or prairie and who has been operating it for a 50-year period, he will unhesitatingly tell you of the changes that have occurred

WHAT CAN WE DO TO ENSURE GOOD PHYSICAL CONDITIONS IN OUR ARABLE SOILS?

The simplest approach to this problem is to study again Nature's methods of developing good structure Practically all soils as far as I know are found to be in better physical condition after they have grown a heavy crop of grass or preferably a grass-legume mixture for a few years.

For generations farmers have realized that for some reason cultivated crops grew better following such a mixture Under grass most soils assume a granular or crumb structure. The exact mechanism of the formation of these crumbs is not fully understood, but the result obtained is universally regarded by soil physicists as the ideal physical state for the growth of most crops It is best developed in soils which are saturated with lime and which contain from 3 to 10% organic matter. Having these amounts of lime and organic matter in the soil, however, will not ensure a good granular structure. Something else is needed. The organic matter must be of the proper type and it must be properly distributed. I have tried to picture to myself how these granules might be formed and why they are so important. Additional evidence is needed, but I feel that the picture is reasonably accurate.

Grass roots are so numerous that in a well-established sod they are seldom over 3 to 5 millimeters apart. These roots ramify the soil in all directions. Each root represents a center of water removal. As water is removed from the soil in contact with the root additional water moves toward the root by capillarity. As water is removed the small fragment of soil between the roots shrinks and is blocked off by the roots. The pressure developed by the capillary forces, compressing the granule from all sides, is great, in many soils it reaches over 5,000 pounds per square inch. As a result these granules become quite dense, their apparent specific gravity ranging from 1.8 to 2.0. The total pore space inside them is small and the size of the pores is very small. Water moves into them slowly but is held firmly. The pores are so narrow that they are easily completely sealed by capillary water and as a result the ventilation of the interior is poor. Consequently, reducing conditions frequently exist on the interior of the granules simultaneously with oxidizing conditions on their surface. This often causes a migration of substances which are more soluble when in the reduced form to the surface of the granule where they are oxidized and deposited. This deposit serves as a cement and helps

to stabilize the granule. Very hard granules of soil may be formed by the compression due to surface tension alone, but such granules are not water stable. When immersed in water, the air-water interface gradually disappears throughout and the granule breaks to pieces.

In forcing its way through the soil many cells are sloughed off the living root and serve as food for bacteria. Eventually, the roots die and are decomposed *in situ*, forming a humified, often water-resistant coating around the granule. The marked difference in color between the surface of such granules and their interior is evidence of this. In many respects it seems to me these tiny granules may be compared to minature "earths". Most of the inhabitants live hear the surface where the "air" is better. In the strongly granulated soil practically the entire mass of clay and silt particles are clumped together in these water-stable aggregates As a result there are two fairly sharply defined groups of pores in such soils, capillary pores within the granule and non-capillary pores between the granules. The non-capillary pores are relatively large. Water enters them readily but is retained only at the periphery. This leaves a continuous series of connecting chambers through which air can readily pass. The water at the periphery is drawn into the capillary pores between the unit particles making up the granules This water constitutes the most closely held reserve in the soil. Such a soil has a permeability approaching that of sandy soils combined with a storage capacity of the heavier textured soils.

Such are the structures which perennial grasses tend to develop in soils[1] Such soils provide optimum growing conditions for most crops. The organic matter constitutes a good reserve of the elements essential for growth. Water and air are present in the proper proportions. With an abundance of food, water, and air, soil micro-organisms flourish and gradually convert the organic reserves into the simpler forms required by crop plants.

Crop roots can easily force their way through the large well-aerated non-capillary pores As a result, a more efficient and extensive absorbing system is developed. The food reserves are concentrated largely on the surfaces of these pores. Once a soil is well granulated and when well-aerated interfaces are formed, roots will tend to follow them instead of forcing their way through the dense aggregates. The effect of the roots is thus accumulative. It is not definitely known how many seasons' growth are required to produce the optimum structure. The major part of the work is probably done in the first few years of growth of the sod.

We have tried to give a picture of the ideal soil structure and of the method which nature uses to develop it. Our problem now is, How can this structure be obtained and maintained under conditions which will enable us to produce all we need of the various cultivated crops? We are living in a mechanical age, we have learned to turn to the engineer whenever we find ourselves in difficulty. Can he be of help to us in solving this problem? In the past I feel that the agricultural engineer has been able to see the temporary tilth which he created with his machines, but he has been unconscious of the effect produced by the continuous use of these machines over a long period

of years. There is no question but that the final result of tillage operations as we now know them is to make the structure of soil worse. If this is true, two possible ways of improving the situation suggest themselves First, it may be possible to develop tillage implements which will accomplish our ends without having such a harmful influence upon structure. This problem is certainly worthy of the serious attention of the agricultural engineer. The second possibility is to reduce the number of tillage operations to a minimum.

This problem will require the close cooperation of the agronomist and the agricultural engineer for it will require for its solution a very complete understanding of the soil and the life history and special requirements of each crop It is interesting to speculate upon the possibility of the agricultural engineer developing a machine which will directly create the ideal structure If such an implement could be devised, and if the effect of the treatment were sufficiently lasting, and if the operation were cheap enough, it might prove feasible If the picture which we have given above of the development of natural structure is correct, however, it is exceedingly difficult to see how an engineer can ever hope to accomplish this task with an efficiency which can compare with that of the natural processes. On many soils in poor physical condition the effect of a costly tillage operation can be almost completely obliterated by a single hard-beating rain.

The place for most useful service of the engineer in this connection it seems to me is in helping to create an environment in which the natural method of developing structure can be most effectively carried out; for example, by the intelligent use of the common agricultural engineering technics in connection with drainage, irrigation, and, under certain conditions, of terracing. From the standpoint of soil physics I think we should look upon tillage operations as we do a surgical operation, indispensable at times, but to be avoided whenever possible

The development of the desirable structure involves the use of growing plants. The more vigorous the growth of the plant, the greater the residues left in the soil and consequently the greater the effect on soil structure. Our scheme should therefore involve all good agronomic practices which will improve the growth of our crops. If the soils are acid, lime will unquestionable help both directly as a result of the influence of the calcium ion on the structure of the soil and indirectly because of its influence on the growth of the crop. Fertilizers and manures should be used generously and wisely for the same reason. There is little evidence to indicate, however, that a good physical condition of the soil can be maintained when planted continuously year after year to intertilled crops even though generously fertilized. The yields of wheat on the Rothamsted Experiment Station have declined and the physical structure apparently deteriorated even when 25 tons of manure per acre per year were applied.

The experience of our better farmers throughout the world, the carefully controlled experiments of our older experiment stations, the accumulated experiences of the older agricultural sections of Europe, all indicate that the most feasible way of maintaining soil structure is by combining arable agriculture with grass land farm-

ing. This may be described as a sort of compromise with Nature in which we cultivate the soil for a few years and produce the food crops which our dense populations require then turn the soil back to nature to recuperate for a few years. We are fortunate in this country in that we have such a large acreage of land well suited for the growth of intertilled crops that we can afford such restorative measures. Not only can we afford them, but there is abundant evidence that if such practices were combined with other well-established agronomic practices that we could produce the same amount of intertilled crops that we are producing at the present time on almost half the acreage we are now using. This can be done without increasing and possibly by decreasing the cost of producing each unit. At the same time we shall be safeguarding the future and handling our soils down to our children in better condition than we received them.

This solution of the problem seems very old fashioned and trite; and perhaps disappointing to those of you who were expecting something new and novel. But it has this virtue, it is a system which has been used extensively throughout the world ever since the time of the Romans, and where it has been intelligently executed it has worked. It has solved the problem of maintaining soils in as good a physical condition as the material and environment at hand would permit.

SOIL CONSERVATION FROM THE VIEWPOINT OF SOIL CHEMISTRY[1]

E. E. DeTurk[2]

THE problem of soil conservation may be considered as the problem of retarding, stopping, or, ideally, reversing the processes which result in soil deterioration from the viewpoint of its crop-producing capacity. Recognizing the inexorability of nature's ways, it may be the part of wisdom merely to offset the damage done by restoring that which can be restored of what was taken away and retard as much as possible the pace at which nature continues her course. As in dealing with all remedial procedures, it is desirable to diagnose the disease before attempting to apply the cure, so, here, it is appropriate that attention be directed to an analysis of soil deterioration into its factors, and to an attempt to characterize these factors, as the first step in the construction of a soil conservation program. Most of this paper will be devoted to diagnostic features in the belief that upon these rest the sound application of curative methods for the ills of unproductive soils.

The writer has been assigned the task of attempting such an analysis with respect to the chemical aspects of the problem. Soil deterioration from this point of view may properly be considered to embrace all of the chemical soil properties which are responsible for impaired yielding capacity, whether they be those of deficiency of essential chemical materials for plant growth, the over-abundance of such materials, the presence in the soil of these substances in unfavorable proportions, the presence of substances definitely toxic to growing plants, or even the development of undesirable physical or biological conditions as a result of chemical causes. Obviously the scope of this problem is too broad for the space available and for the capabilities of the writer; it becomes necessary, therefore, to limit the discussion to soils restricted as to geographical location and also as to the environmental conditions of their development.

Soils may be divided on one basis into two great groups, pedalfers and pedocals. While these are defined on the basis of certain chemical characteristics of their profiles, they are distinguished as to conditions of development chiefly by the relative abundance or scarcity of water. Because of the failure during development to lose soluble products of weathering, certain soils in arid environments when brought under cultivation with irrigation may deteriorate rapidly through the development of white or black alkali, or of "nitre spots" —a deterioration characterized by the over-concentration of materials, for some of which the eastern farmer pays out money in order to add them to his soil. Again, large areas of soil in the western plains

[1]Contribution from the Division of Soil Fertility, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Also presented at the annual meeting of the Society at Washington, D. C., November 19, 1936, as part of a symposium on "The Scientific Aspects of Soil Conservation".

[2]Professor of Soil Technology.

have deteriorated as a result of denudation by overgrazing. But this problem is largely physical and biological, and has also important social and economic aspects. Some of you may be more interested in these problems than in that which is to follow, but their discussion by a novice would be of little profit.

This paper, then, will be concerned with soils of the humid temperate region particularly as exemplified by Illinois conditions. With its scars of three or more glacial advances mostly blanketed with loess, its north-south extension of four hundred miles and its location at the border line between the corn belt prairie and the forest region to the east, Illinois presents a wide array of soil problems, the solution of which has applications beyond the borders of the state.

THE RÔLE OF NATURE IN SOIL DETERIORATION

SOIL DEVELOPMENT

A soil may be unproductive on account of physical, chemical, or other conditions aside from plant nutrient requirements. On the other hand, it may owe its infertility to failure to supply the crop with its essential soil-derived elements at suitable rates and times. Under humid temperate conditions both of these types of soil deficiency are to be met.

Soil deterioration is brought on by the natural processes of soil development, which may be modified in kind, or more frequently, in relative rate of progress, by agricultural practices when land is brought under cultivation. In general, the changes comprising soil development are more far-reaching and less amenable to correction than man-made changes effected by farming. Soils vary in productive capacity when first broken out of the virgin state; they become exhausted at different rates when cropped; and they are not capable of being brought up to equally high productive levels by any feasible soil improvement methods. These differences in soils are fundamental. They are the product, in the first place, of the parent materials out of which the soils have been made, and in the second place, of the forces to which these parent materials have been subjected during the course of their development. These forces, and their relative intensities, are the product, chiefly, of the climatic conditions, the topographic position, and the native vegetative cover.

The development of a soil, as Marbut (9)[3] has emphasized, is a constructive process. But the continued action of the same forces, where no accretion occurs by alluvial deposition or by lowering the profile through natural erosion, is capable of reducing a soil to a very low level of producing capacity, particularly under conditions of poor drainage. Such conditions are found in the nearly level uplands of Illinois. Bray (2) states that, "Within a distance of 60 miles from Mason to Fayette county in Illinois, occurs a gradual development of profile characteristics. The field and laboratory studies carried on in Illinois, particularly since 1922, led to the conception reported by Norton and others (10) of five stages of development as recognizable in Illinois soils. The prairie soils on very gently undulating topog-

[3]Figures in parenthesis refer to "Literature Cited", p. 111.

raphy vary progressively from Hartsburg silt loam, stage 1, a dark-colored, highly productive, immature soil with carbonates at 33 inches, to Cisne silt loam, stage 5, an old light-colored, acid, unproductive claypan soil."

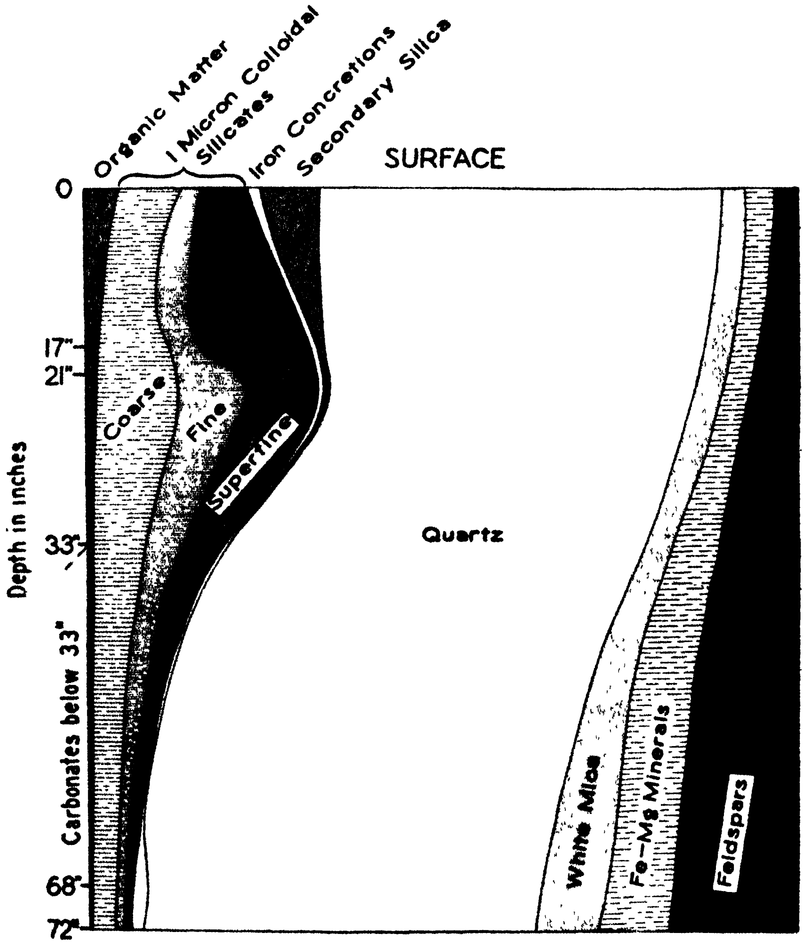

FIG. 1.—Gross mineral composition of a youthful, fertile, dark-colored prairie soil; Hartsburg silt loam, stage 1 Width of chart equals 100%.

Figs. 1 and 2, respectively, show the mineral composition of the first and last of these five stages (2). From the viewpoint of the present discussion it may be considered that stage 1 (Fig. 1) represents the climax in productive power, and that deterioration in producing capacity begins at approximately that point. Weathering of primary silicates has progressed rather far, as indicated by the lessened amounts remaining in the upper horizons. The secondary colloidal silicates produced are still found for the most part in place, that is, in decreasing amounts from the surface downward, although down-

ward movement has begun. The other products of weathering the soluble basic ions have been leached out except insofar as they are retained in the colloidal complex, chiefly in replaceable form. Leaching has been barely sufficient to remove carbonates from the upper 33 inches, leaving the soil nearly neutral in reaction. Below 33 inches carbonates are present. Organic matter is comparatively high. The neutral reaction has prevented its leaching as "humus," freezing winter temperatures have reduced the opportunities for biochemical decomposition, and warm moist summers, with abundance of mineral plant food materials, all have contributed to maximum production of organic matter by plant growth. This, then, is a productive soil which nature has prepared to withstand many years of cropping with minimum deterioration.

In Fig. 2 is seen the result of natural soil deterioration under similar conditions of climate, topography, and vegetation. The Illinoian gumbotil underlying Cisne silt loam at 40 to 50 inches has retarded drainage during soil development more than in the case of Hartsburg silt loam on similar topography. The processes are not essentially different from those which brought the soil up to a high state of productivity; they have continued but at modified relative rates. Primary mineral weathering is slowed down but has penetrated to greater depth. Downward movement of the colloidal silicates out of horizon I has continued, but owing to partial stoppage of channels of movement by earlier incipient accumulation, and other possible causes, excessive concentration in upper horizon II, just below 20 inches, has resulted in the formation of an impervious claypan. Loss of colloidal material from horizon I, with consequently lowered exchange capacity in that horizon, has reduced the ability of this stratum to hold the basic ions essential for plant growth. Their removal has increased the acidity of this stratum and leaching has, in addition, removed carbonates as well as replaceable basic ions to much greater depth or entirely out of the solum. All of these conditions have combined to render horizon I—the most important zone for plant feeding—less capable of supporting a vigorous vegetation without a correspondingly great reduction in its facilities for biochemical decomposition of the plant residues, hence the gradual depletion of organic matter. The evidence indicates how effectively nature can accomplish soil depletion, given time and the right conditions, without the intervention of man and his agricultural pursuits.

POTASSIUM

Further evidence of natural soil depletion under the conditions described above may be gained by a study of the status of soil potassium in the surface soil at the extremes of development, stages 1 and 5. Table 1 shows the total potassium content of the whole (surface) soil of the two representative types and its distribution among the component parts of the soil, namely, the non-colloidal portion or primary minerals, the colloidal portion, and in three different size grades into which the 1-micron colloid was fractionated. All of these analyses are of the material freed of replaceable potassium. DeTurk and Bray state that "A decrease of 10 or 15% (13.7 in this case) in total potassium con-

tent in changing from a young to a very old soil would not in itself appear to be a serious matter, considering the high total potassium content. Its importance becomes apparent only upon allocation of the various losses among the different mineralogical soil constituents. The non-colloid fraction, consisting of primary minerals, and which

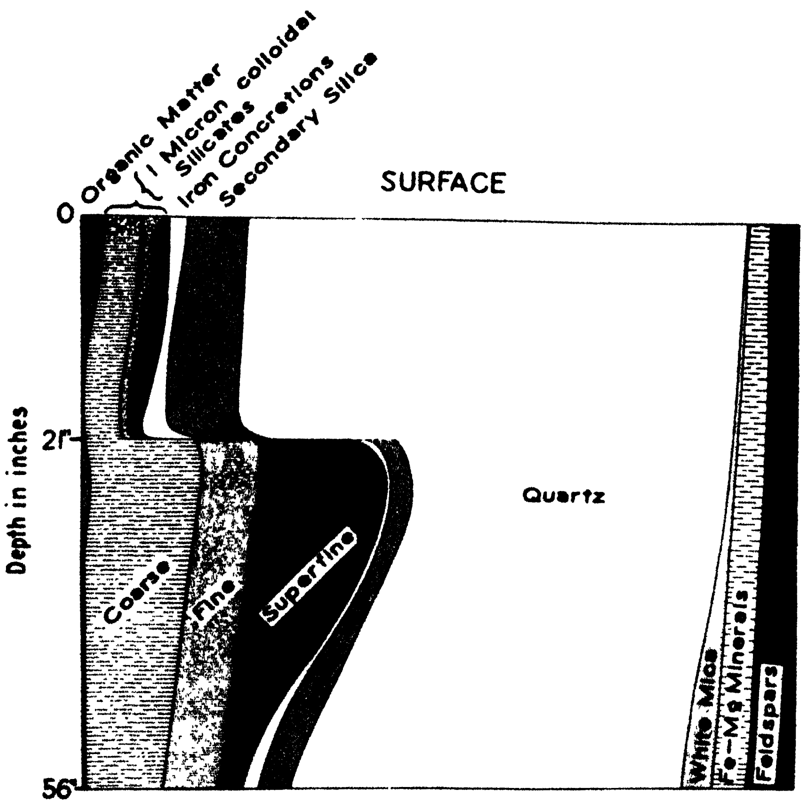

FIG. 2. Gross mineral composition of a mature, infertile, light-colored, claypan prairie soil: Cisne silt loam, stage 5.

is of least significance as an immediate source for crops, has lost but 6.5%, while nearly half (47.2%) of the colloid potassium has disappeared in the transition from stage 1 to stage 5. Of the important potassium minerals, feldspars are found chiefly in the non-colloid size range and change slowly, being resistant to weathering Micas, on the other hand, which occur chiefly in the fine silt and coarse colloid fractions, decrease rapidly with progressive development The potassium mineral of the coarse colloid, the mica-beidellite association described by Bray (2), contains potassium and magnesium and has a silica-sesquioxide ratio of 3.0. It is our belief that this material loses beidellite to the superfine fraction by mechanical breakdown, and by complete breakdown could undoubtedly be completely converted to beidellite with accompanying loss of its potassium content. The losses of the potassium contained in these colloidal size ranges occur

partly by leaching, partly by degradation of the coarser particles to finer sizes and subsequent leaching of newly exposed potassium, and partly by downward movement of the colloid itself out of horizon I. It is the loss of this fine silt and colloid potassium which is chiefly responsible for potassium deficiencies."

TABLE 1.—*Loss of surface soil potassium with advancing development.*

	Stage 1 immature Hartsburg silt loam, lbs. per acre	Stage 5 old Cisne silt loam, lbs. per acre	Loss	
			Lbs. per acre	%
In whole soil	30,200	26,060	4,140	13.7
In non-colloid . . .	24,880	23,250	1,630	6.5
In colloid*:	5,320	2,810	2,510	47.2
Coarse colloid	2,920	2,390	530	18.2
Fine colloid . . .	1,060	230	830	78.3
Superfine colloid.	1,340	190	1,150	85.8

*Diameter coarse, 1.0-0.1 micron; fine 0.1-0.06 micron; and superfine, <0.06 micron.

Table 2 illustrates the relative loss of coarse, fine, and superfine colloid from the surface soil in passing from stage 1 to stage 5. In the two columns at the right, is shown the reduction in potassium content with decreasing particle size, and also with advancing development within a given size range. Returning to Fig. 2, it is appropriate to point out that in stage 5 white mica, the more important (agriculturally) of the primary mineral forms of potassium, has practically disappeared from the surface and is no longer available as a source of replenishment to the replaceable form.

TABLE 2.—*Change in amount and K-composition of colloid with maturity.*

Colloid size, micron	Amount of colloid in soil		K-composition of colloid	
	Stage 1 Hartsburg, %	Stage 5 Cisne, %	Stage 1 Hartsburg, %	Stage 5 Cisne, %
1.0–0.1. . . .	8.1	8.3	1.80	1.44
0.1–ca 0.06	3.3	1.1	1.60	1.06
<0.06 .	10.6	2.6	0.63	0.37

The discussion now turns to relative deterioration during soil development under well-drained conditions. The stamp of advancing maturity is not so sharply impressed upon these soils as in the case of the poorly drained soils. Only partial data have been secured and these are given in Table 3 for two profiles, that of Clinton silt loam and of Ava silt loam. These types represent stages 2 and 5 in development, respectively. The extent of weathering of primary minerals, as indicated by the total colloid content does not differ greatly in the two profiles, nor does the extent of downward movement of the colloids. There has been downward movement in both cases, but even in the stage 5 profile there is no zone of high concentration with its resulting claypan. The most distinct evidence revealed by these analysis of the more advanced development of Ava silt loam is the

great leaching loss of replaceable bases, with marked desaturation of the exchange complex and low pH values throughout the profile.

TABLE 3.—*Comparative analyses of well-drained profiles in early and late stages of development.*

Depth, in.	Colloids <1 micron, %	Base-exchange capacity, M.E.*	Total replaceable bases, M.E.*	Degree of saturation, %	pH
		Stage 2, Clinton silt loam, Knox County			
0–5	11.8	13.0	11.8	91	6.41
5–11	17.0	14.0	10.0	71	5.72
11–15	22.8	18.4	14.4	78	5.85
15–28	31.3	26.0	19.4	75	5.40
28–37	30.7	27.4	17.8	65	4.98
37–45	28.6	23.8	17.3	73	5.00
45–56	23.2	21.0	17.1	81	5.82
56–67	19.0	18.9	17.4	92	6.73
67–76	18.0	16.6	16.2	97	6.84
		Stage 5, Ava silt loam, Jefferson County			
0–5	8.8	9.4	4.3	46	5.26
5–10	14.3	11.5	5.7	50	5.44
10–21	23.7	20.6	6.0	29	4.81
21–31	31.1	27.0	8.8	33	4.68
31–40	27.3	28.6	9.1	32	4.81

*Milligram equivalents per 100 grams soil

The disappearance of soil potassium affords a means of indicating the progress of chemical weathering. In Table 4 it will be seen that in passing from stage 2 to stage 5 there is a loss of total potassium ranging from 16 to 36%. Since potassium occurs chiefly as primary minerals and is not a constituent of secondary minerals except in the replaceable form, the disappearance of this element is indicative of destruction or alteration of the minerals. The loss occurs under either forest or prairie cover and under both good and poor drainage conditions, but is greater under the poorly drained conditions of level topography. The influence of topography is further emphasized by the data at the bottom of Table 4.

TABLE 4.—*Effect of stage of development, vegetative cover, and drainage on total potassium content of surface soil.*

	Immature, stage 2, Knox County, % total K	Mature, stage 5, Effingham County, % total K	Loss, %
Well-drained forest soil	1.80	1.42	21
Level, poorly drained forest soil	1.69	1.08	36
Well-drained prairie soil	1.63	1.37	16
Level, poorly drained prairie soil	1.48	1.19	20

	Rolling	Gently rolling	Undulating	Flat
Old forest soil, stage 5, Effingham County	1.57	1.42	1.31	1.08

The possibility of a rejuvenating effect of natural erosion is recognized, but the evidence indicates that it is a minor factor compared to the differential weathering rates discussed above.

The apparent anomaly of excessive removal of carbonates and development of distinct acidity in well-drained soils, but with relatively small reduction of total potassium, in contrast to the greater weathering of primary minerals and lowering of total potassium content in poorly drained soils is clarified when it is considered that carbonates and replaceable bases are readily soluble in soil water so that the rate of removal depends largely upon the rate of percolation of water through the soil. The relative rate of leaching will thus be more rapid from well-drained soils, even tho, on account of run-off, the amount of water passing through may be reduced. The primary silicates, on the other hand, are difficult of solution, their potassium and other bases being liberated only upon alteration of the minerals to secondary colloidal silicates, largely through water action. The rate at which this process goes on depends, therefore, upon the proportion of the time during which these minerals maintain contact with the hydrolytic reagent, water. This time of contact is greater the poorer the drainage conditions, and the actual leaching of the solubles becomes a very minor affair compared to the rate of liberation, which, in any event, is much slower.

It has been seen that two dominant processes of soil development, namely, weathering of minerals to form base-exchange material, and downward movement of the latter, result in progressive depletion of the surface soil of this important constituent. In Fig 3 are shown, in decreasing order, the base-exchange capacities (whole bar) of the more extensive soil types in Illinois This arrangement by decreasing values approaches that which would be obtained by placing them in order of advancing development (6).

Up to this point there has been presented evidence, chiefly chemical, of the progress of soil development. What is the evidence of actual deterioration of the soil as measured by its ability to produce crops? If the 25 Illinois soil experiment fields be arranged in order of decreasing productive power as indicated by the relative yields of digestible nutrients on untreated check plats (black portion of bar, Fig. 4 (1)), it is found that a ranking occurs similar to that obtained when they are arranged in order of base exchange capacity. That is, the less developed soils are represented by the fields to the left, while those to the right are on soils in the most advanced stages of development. The same or very similar soil types occupy corresponding positions in Figs. 3 and 4.

ORGANIC MATTER

Changes in organic matter brought about under natural conditions have a definite bearing upon productivity and soil conservation measures. Being of atmospheric origin with respect to two of its important constituents, carbon and nitrogen, it is found in greatest amount near the surface and decreases with depth. Under natural conditions organic content increases to a peak which is usually attained in the early stages of profile development in which horizons are

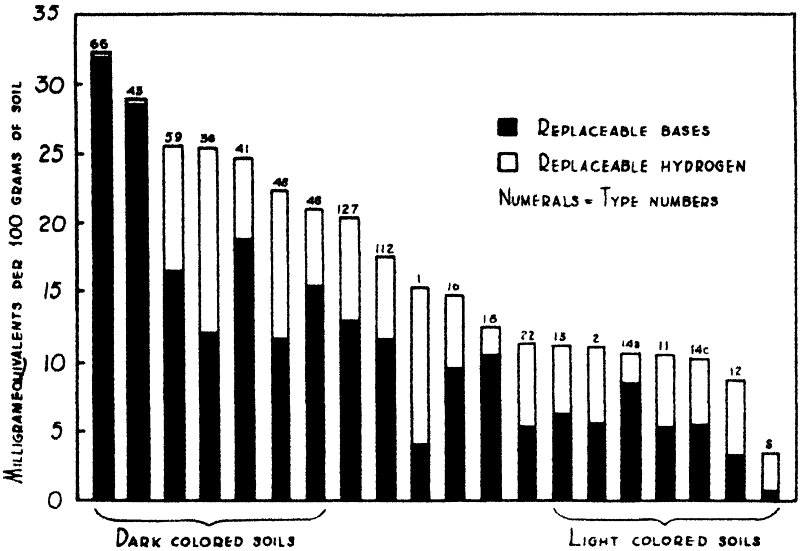

FIG. 3 - Base exchange capacities of Illinois surface soils.

beginning to emerge as recognizable but not sharply defined units Thereafter occurs a decline to fairly low amounts in the most advanced stages of development This subject is closely associated with biological problems It is well known that native vegetative cover is a most important factor affecting the organic content of soils, grassland cover bringing it to a relatively high peak in early maturity compared to a lower peak under forest vegetation The decline attending subsequent soil development tends to equalize organic matter content again, so that in the most advanced stages the prairie soils contain but little more than those under forest cover

PHOSPHORUS

The phosphorus problem is more complex and less understood than many other aspects of soil deterioration and its correction. This is true in spite of a great amount of research work by many workers extending over many years, and it applies to the changes that occur during natural soil development as well as deficiencies which result from cropping. The relative amount of total phosphorus in soils is small, usually less than one-twentieth of 1%, and although drainage and percolation studies consistently indicate a very low degree of leachability, the results of several thousand analyses of Illinois soils, as well as data of other workers, indicate a definite trend toward lower total amounts with advancing soil development. But this information alone is of little value because, in the first place, the amount present in the entire solum of most soils, if freely utilizable by crops, would suffice for several centuries, and in the second place, the total amount present is not a good index of the relative sufficiency for plant growth. To trace the fate of those forms which are readily utilizable by growing plants and their decrease accompanying soil development, either

by leaching or by conversion to less available forms, would be of more value.

Thirty years ago Whitson and Stoddart (14,13) emphasized the common observation that acid soils were generally in need of phosphate fertilizers and showed that the ratio of iron and aluminum phosphates to calcium phosphates was higher in acid soils than in non-acid soils. They suggested the fixation of phosphates to difficultly available forms by hydrated iron and aluminum compounds as hydrated phosphates of these metals. Within the last decade attention again has been focused on this matter. The work of Truog and his present and former associates is particularly helpful.

Ford (7) found that prolonged leaching of certain Kentucky soils with carbonic acid and with H_2SO_4 at pH 3 showed solubility similar to that of dufrenite ($Fe\ PO_4 \cdot Fe(OH)_2$). Later (8), he showed that limonite or göthite, hydrated ferric oxide, fixed phosphate ion in a compound not soluble in H_2SO_4 at pH 3 and difficultly available to plants; that PO_4 ion fixed by Ca or Mg was soluble in the same reagent and available to plants; and that $FePO_4$ and $AlPO_4$ precipitated by ferric salts or by $Fe(OH)_3$ was intermediate. He also showed that hematite, an anhydrous ferric oxide, did not fix PO_4 ion and that prolonged heating of göthite at 185° C destroyed its ability to fix that ion.

Scarseth and Tidmore (11, 12) found that soil colloids fixed PO_4 ion in inverse proportion to the SiO_2/R_2O_3 ratio, i. e., directly in proportion to the relative content of R_2O_3, and that availability of native soil phosphorus was inversely proportional to the relative content of R_2O_3. They also found that plants growing in certain clay soils responded to soluble phosphates only when the phosphate added was in excess of the fixing capacity of the soil, and that the efficiency of phosphate fertilizers decreased with time of contact with soil. They found further that $CaCO_3$ freshly added to soil lowered phosphate availability to crops, but that the opposite effect was produced after the disappearance of carbonate and the absorption of the Ca in the exchange complex. It is noteworthy that this work was done in a region where the nature of soil development is lateritic and that the R_2O_3 of the soil colloids may have included considerable free hydrated oxides of iron and aluminum.

Cook's (3) findings using a bentonite colloid were essentially in harmony with those just mentioned, although he approached the problem from a somewhat different angle. Observations in southwestern Illinois where soil profiles were developed on three superimposed loess sheets of different ages, each feathering out toward the east into the next older one, revealed large amounts of phosphorus soluble in 0.7 N HCl in the soil on the youngest loess sheet, lesser amounts on the second, and a very low level of soluble phosphate on the oldest. Numerous other studies on Illinois soils have revealed a lowering of the amount of easily acid-soluble phosphorus with advancing soil development. Increasing soil acidity with advancing soil development has already been referred to, and there is abundant evidence of increasing salt-soluble iron with increasing acidity, as witness the thiocyanate test.

All of these observations fit together to indicate that nature undisturbed in the climatic region under consideration will eventually wear out a soil with respect to its phosphorus as well as in other respects. The sequence of events appears to be about as follows: With the advanced stages of soil development the exchange complex is gradually deprived of its absorbed alkali and alkaline earth bases, accompanied by increasing acidity Under these conditions there is opportunity for iron and aluminum to exhibit their basic properties and if in this they take the form of hydrated oxides, the fixation of any phosphate liberated from calcium phosphate minerals in the acid environment is to be expected. Of the mechanism involved, the present occasion does not permit a discussion. It may be noted that the stability of the secondary colloidal silicates is thought to be lowered by acid conditions, and their disintegration as well as downward movement may contribute to the loss of base-exchange capacity in the surface of old soils. Returning to Figs 1 and 2. it will be seen that horizon I of stage 5 has gained noticeable quantities of secondary silica and iron in the form of concretions, both of which, together with aluminum, are the products of such disintegration. Is it not reasonable to suppose that the disseminated iron, before it was concentrated into concretions, might have occurred in the form of hydrated oxides which could fix any soluble phosphates? And if some soluble phosphate escaped fixation, the decline in total phosphorus suggests that it may have escaped in the drainage waters.

Organic phosphorus is mineral derived, and under natural conditions tends to accumulate near the surface at the expense of strata immediately below as well as at the expense of mineral phosphates in the surface. Naturally the accumulation is more pronounced in soils of high organic content, as the grassland soils, giving a total phosphorus profile tending to be higher in horizons I and III than in II. Some green manuring crops owe their value in part to conversion of difficultly available mineral phosphates to easily available forms. About half their total phosphorus is soluble inorganic phosphate. Do they owe their value to this half alone, or does the organic portion become available promptly in the soil? The "organic" portion is still orthophosphate, even tho linked into a phosphatid or a nucleic acid molecule. Does it retain these linkages or assume new ones when it becomes a part of the more permanent stock of soil organic matter? We cannot answer these questions, but it may be noted that there are many areas of peat and muck soils which contain twice as high a percentage of total phosphorus as the rank and file of mineral soils, and which nevertheless, exhibit deficiency in available phosphorus by responding to phosphate fertilizers in crop production.

Perhaps too much space has been devoted to the rôle played by nature in exhausting soils. But it should be emphasized that these natural forces, exerted over geologic periods, have been the dominating influence in making a soil what it is today. A few centuries are but a moment in the life of a soil and it is not to be expected that man's occupation of the land during so short a time would produce effects

as deep seated as those brought about by soil development.[4] Attention will now be directed to some of the effects of cropping in accomplishing soil depletion.

THE RÔLE OF MAN IN SOIL DETERIORATION

The exhausting influence of cropping may be shown by changes in crop yields, but to be of significance such measurements need to be made over a long period of time in order that trends may be discerned through the irregularities produced by varying seasonal conditions. Crop yields, however, do not reveal soil changes, but only certain of the effects thereof. The soil may be examined as to chemical and other properties after varying periods of cropping. Study of the soils of cropped fields in comparison with nearby uncropped soils also reveals in part the changes produced. In general, it may be said that cropping tends to accelerate some of the processes which have been going on at a slower rate under natural conditions. In addition, the removal of chemical elements in crops harvested from the land adds to the depletion of the more easily available portion of those elements.

The yields of corn grown in succession on the same area on the Morrow plots at Urbana are typical of crop results which could be cited from Pennsylvania, Ohio, Missouri, Rothamsted, and other places, and illustrate the decline of crop-producing ability under severe cropping systems. The average annual yields on the Morrow plots during four successive 12-year periods, 1888–1935, with no soil treatment, were 39.8, 29.8, 25.9, and 22.9 bushels, respectively.

COLLOIDS AND BASE EXCHANGE

It was shown earlier that loss of colloidal material from the surface soil is an accompaniment of soil development, that mechanical breakdown of coarse colloid occurs, and that ease of downward movement increases with decreasing particle size so that the colloid loss from the surface soil is predominantly that of very fine material. The frequent disturbance of the surface stratum of cultivated soils in tillage operations tends to lower its colloid content by particle disintegration to smaller sizes and by aiding downward movement. This is shown in Table 5, by comparison of the soil of the continuous corn plot with that of the grass border. A part of this loss may, of course, have been due to oxidation of organic colloidal material in the cultivated soil. A fractionation of the colloids shows that most of the 18.4% loss is in the size range smaller than 0.06 micron. The use of fertilizers (MLP) has not affected this loss. Further evidence is found in the base-exchange capacities of surface soil samples taken in 1904, 1913, 1923, and 1929 (Table 6). Plots 3 NW and 3 NE are duplicate check plots, the latter being on lower, somewhat heavier soil, a situation reflected in the exchange capacity values. The replaceable bases have been leached more rapidly from the cultivated soil than from the border, but the percentage saturation has not suffered proportionately because of the compensation of lowered capacities.

[4]One important exception must be made to this statement, namely, erosion which man, through improper management, has permitted to devastate vast areas.

TABLE 5.—*Morrow plots, surface soil change in 1-micron colloid.*

Plot	Colloid, %
Grass border	21.7
3 NW, check	17.8
3 SW, MLP	17.6
Average loss, cultivated soil	4.0
Loss, % of border	18.4

TABLE 6.—*Morrow plots, chemical changes in surface soil of untreated continuous corn plot.*

Plot	Year sampled	Exchange capacity, M.E.	Replaceable bases, M.E.	Percentage saturation	pH
3 NW, check	1904	21.6	13.9	64	5.5
	1913	21.1	12.4	59	5.5
	1923	21.4	11.5	54	5.4
	1929	20.6	11.2	54	5.2
Grass border	1929	24.1	14.0	58	5.4
3 NE, check	1904	23.9	16.1	67	5.5
	1913	22.7	13.9	61	5.5
	1923	22.0	13.3	60	5.4
	1929	19.8	11.4	58	5.2
Grass border	1929	26.3	19.6	75	5.5

A comparison of cultivated and uncultivated soils corroborates the evidence of the Morrow plots. Twelve pairs of soil samples, each consisting of a sample from a cultivated field and a roadside sample a few feet distant, were subjected to exchange capacity determination. In 7 cases out of 12, the capacities of the cultivated soils were lower by varying amounts, averaging 1.8 M. E. per 100 grams of soil, a fall of 15%, while in only two cases were there apparent gains of 1 or more M. E. Increased leaching under cultivation was shown by lowered replaceable base values and consequently lowered percentage saturation in the cultivated soils, except in four cases where the known history or the vigorous growth of clovers indicated that limestone had been applied.

ORGANIC MATTER

Just as native forest and grass cover establish distinct soil organic levels suited to the soil climatic environment, so each rotation system followed consistently in farming tends to produce a state of equilibrium in the soil at which the organic matter content will change but little. Since oxidation of organic matter is one of the natural soil processes accelerated by cultivation, the crop rotations commonly practiced induce a shift in soil organic matter toward lower levels than those of the virgin state. Plot 3N (Table 7) illustrates such a

transition in progress, while in plots 4S and 5S the organic matter level is approximately stationary, probably somewhat lower than in the virgin state. The rotations had been underway 37 years and the manurial treatments 9 years at the time of the 1913 sampling. One of the very substantial gains that could be made for soil conservation would be implanting in the mind of the farmer on the land the conviction that with well-driected arrangement of cropping systems he could greatly retard the wasteful dissipation of organic matter.

TABLE 7.—*Morrow plots, organic carbon in surface soil, pounds in 2 million of soil.*

Plot	1913	1923	1933
Untreated Soil			
Plot 3N, continuous corn	42,160	38,870	36,860
Plot 4N, corn, oats	47,320	44,180	43,060
Plot 5N, corn, oats, clover	52,740	51,440	49,980
Manure, Limestone, Phosphate			
Plot 3S, continuous corn	49,660	46,990	45,440
Plot 4S, corn, oats (s. c.)*	52,710	53,610	53,780
Plot 5S, corn, oats, clover	58,460	57,320	59,410

*Sweet clover green manure begun 1916, also seeded on plot 4 N untreated, but fails.

PHOSPHORUS

The low water solubility of soil phosphorus has protected a very small concentration against complete exhaustion under natural conditions, but it has not prevented the farmer from depleting the readily available supply in a few generations. Plant residues return phosphorus mainly to the surface soil, while root systems remove it from the surface and also from greater depths. As a net result there is a tendency for depletion caused by cropping to occur first in the strata immediately below the plowed surface. This process may, in exhaustive cropping systems, merely supply the needs of the crop harvested from year to year, resulting eventually in the depletion of the surface soil also, or in better designed rotations, it may suffice for the needs of the crops removed and in addition allow a build-up of available phosphorus in the surface stratum at the expense of the strata below, a tendency noted earlier regarding total phosphorus under natural conditions. The progress of available phosphorus depletion is illustrated by the soil of the continuous corn area of the Morrow plots, sampled in 1904, 1913, 1923, and 1933 (Table 8). Further evidence is obtained by a study of easily acid-soluble phosphorus in 152 soil samples taken in pairs, a roadside uncultivated sample, and one from an adjacent cultivated field. These 76 pairs of samples were taken from several counties and represented a wide range of soil types. Of 46 uncultivated surface samples containing less than 25 pounds an acre of acid-soluble phosphorus, 33 corresponding cultivated samples remained the same, while 13 showed a gain, but all of the subsurface (7 to 20 inches) cultivated soils showed

either a loss (24 cases) or no change (22 cases) as compared to the uncultivated samples.

TABLE 8.—*Changes in acid-soluble phosphorus with cropping to continuous corn, unfertilized, on Morrow plots.*

Date sampled	Pounds of phosphorus soluble in 0.7 N HCl pounds in 2 millions of soil		
	0–6⅔ in	6⅔–20 in.	20–40 in.
1904	35	No data	No data
1913	50	50	100+
1923	30	30	100+
1933	30	<25* <25*	70† 100+† 100+†

*Upper figure for 6⅔–13⅓ in., lower for 13⅓–20 in.
†Upper figure for 20–26⅔ in.; middle for 26⅔–33⅓ in.; lower for 33⅓–40 in.

Of the 30 pairs in which the roadside surface sample gave a high test, about half showed little change in the adjacent cultivated field while half showed distinct losses. But again, with four exceptions, the status of the comparable subsurface soils from the tilled fields was either a loss (15 cases) or no change (11 cases). These observations indicate that phosphorus depletion of farmed soils occurs, first in the subsurface horizons, then followed in varying degree by the surface soil, depending on the balance between crop removals and restoration in phosphorus-containing residues or other added materials.

OTHER ELEMENTS

Potassium differs from phosphorus in its soil status chiefly in the large reserves present in primary silicate minerals and in the fact that its rate of liberation from these reserves is to a great extent independent of soil management practices. Practices resulting in comparatively large yields, built on the conception which prevailed for many years that with abundant mineral forms of soil potassium the chief problem was one of liberation, bring about only the more rapid depletion of the supply being liberated, without a corresponding increase in rate of release. The inevitable outcome is to hasten rather than to retard the appearance of potassium deficiency.

The question of so-called minor elements is in many respects an academic one, although in certain restricted areas abnormally high or low amounts of various of these elements constitute a real factor in soil deterioration.

CONSTRUCTIVE MEASURES

As indicated in the beginning the emphasis has been directed chiefly to a characterization of some of the ills of soils and their causes. This leads to the question of remedies. It is not the intention to present a list of reconstructive measures for the restoration of depleted soils. It is the purpose rather to mention certain principles and show their relation to the problem of conservation. It will then

be left to the soil conservationist to fit appropriate remedial measures to the deficiencies.

In Fig. 4 are shown the improvements in yielding capacity brought about by good soil treatments on 25 Illinois experiment fields, superimposed on the graphs showing yields without fertilizers (1). The in-

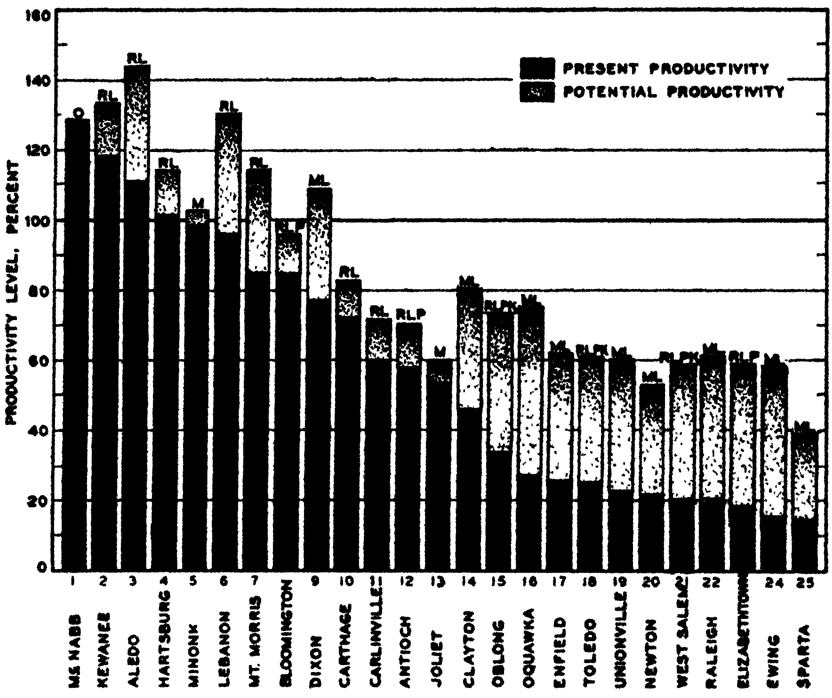

FIG. 4.—Possibilities of raising the productivity levels of Illinois soils.

creases shown are those produced by the soil treatments found to be most advantageous on the different soils. The treatments may not be ideal, but they indicate the relative potentialities of these soils. Although the yields on the poorer soils have been more than doubled, they are at best only 50 to 60% as high as on the better soils. They cannot be brought up to the higher production levels because nature has done to these soils what man cannot undo. They no longer have their original holding capacity for the basic elements. They no longer have the supplying power for the inorganic salts required. They no longer have facilities for controlling water relations and consequently are susceptible to the vagaries of the weather. Certain things can be done. The base capacity is saturated by liming and soil acidity corrected. The quality, but not the quantity, of organic matter, with its associated nitrogen may be partially or wholly restored by rotations carrying suitable soil conservation crops. Fertilizers make good the shortage of inorganic nutrient salts. Then, when a good season comes, a bumper crop helps boost the average of the lean years. It is well to

recognize the limitations of the association which consists of a soil and its climatic environment. The case just cited is one in which nature has carried soil deterioration beyond the ability of man fully to restore its productiveness.

It is the less mature soils, still endowed with moderate to high crop-producing *potentialities*, which the farmer, by exhaustive cropping methods, has reduced from high to low *actual productiveness* in the course of a few generations. This type of soil depletion is primarily one of reducing the supplying power of the soil for essential mineral elements to too low a level as to rate, or to lowering the quantity and quality of the soil organic matter with its nitrogen content, or both. Associated with these changes there usually occurs an increase in soil acidity.

Losses of essential elements by leaching as well as by crop removal may contribute to soil depletion due to farming. Lysimeter studies have been made at Illinois which demonstrate the important rôle of individual crops and their combination in rotations in the control of leaching loss. By means of lysimeters large enough to allow growth of crops to maturity, and walls extended to prevent runoff, the amount of leaching under natural rainfall is exaggerated, and the relative effects of different crops in reducing losses by leaching are made to stand out in sharp relief. Individual crops vary widely in the extent to which they reduce water percolation through the soil (Table 9). Alfalfa, the only perennial used, was found to exert the greatest retarding effect followed by other close-seeded crops, then by corn and, finally, bare soil. The behavior of rotations reflects that of the crops composing them. The corn-wheat-timothy rotation ranks out of its expected order, approaching bare soil, because this rotation permits only poor growth. The timothy does not form a sod and the wheat does not stool. In wet years the growing crop exerts less influence than in dry years and results are somewhat erratic, though they exhibit similar trends.

TABLE 9.—*Percentage of rainfall appearing as drainage under different crops singly and in rotations.*

Crop	1928–29 (wet year)*	1931–32 (dry year)†
Alfalfa	9.3	0.0
Oats	20.0	5.5
Red clover	26.7	8.8
Wheat	23.0	11.1
Corn	25.9	15.3
Bare, cultivated	39.0	24.0
Corn, oats (sweet clover)	22.0	8.7
Corn, wheat, red clover	28.2	10.7
Corn, oats	32.0	16.7
Corn, wheat, timothy	33.5	21.3

*Rainfall, 45 inches.
†Rainfall, 30 inches.

The leaching of mineral elements (Table 10) parallels the amounts of drainage water. This is not true of nitrogen, the leaching of which is influenced also by the nitrogen-fixing capacity of the legumes in

the rotation, so that high-legume rotations not only provide large amounts of nitrogen used by crops but at the same time permit more nitrogen to be removed in leachings than non-legume rotations (Table 11). No detectable changes have occurred in the nitrogen content of the surface soil during the 8 years of the experiment. If the entire depth be considered, there is indication of a gain in the case of alfalfa which may be in excess of the experimental error. The remarkable beneficial effects of legumes are emphasized by the production of a wide spread in the corn yields (compare corn-oats rotation with and without sweet clover green manure, Table 11) within a short time under conditions that without them are capable of reducing yields quickly to very low levels, in spite of sufficient quantities of lime and mineral elements which were supplied. This beneficial effect may be attributed to nitrogen addition and to improvement in the nature of the soil organic matter rather than to large permanent increments in amount. Such improvements are reflected in bio-chemical activities, one example of which is given, namely, nitrifying ability. It is obvious (Table 12) that rotations, the growing of legumes, soil reaction, and adequate amounts of the essential mineral elements all contribute to this important soil function (4).

TABLE 10.—*Average annual removal of mineral elements (pounds per acre) in drainage from lysimeters, 1926–1933.*

Cropping system	Ca, 1926–33	Mg, 1926–33	K, 1933–35	S, 1926–33	Acre inches of drainage water, 1926–33
Corn, wheat, timothy....	141	68	19	58	12.5
Corn, oats...........	148	72	24	59	12.0
Corn, oats (sweet clover)	119	60	11	51	9.9
Alfalfa...............	91	48	10	39	7.0
Bare..............	181	89	22	58	15.0

TABLE 11.—*Annual nitrogen removal from lysimeters in crops and drainage, pounds an acre, 1926–33.**

Cropping system	Corn yield, bu. per acre	Acre inches of drainage water	Nitrogen removed		
			In drainage water	In crops	Total
Corn, wheat, timothy .	38.0	12.5	9.2	29.1	38.3
Corn, oats.............	29.0	12.0	9.6	46.0	55.6
Corn, oats, (sweet clover)	58.0	9.9	13.6	76.4	90.0
Alfalfa (tons)	3.8	7.0	3.9	151.5	155.4
Bare, cultivated........	——	15.0	35.1	0.0	35.1

*Average annual rainfall, 39 inches.

It has been seen that nature and man have contributed in varying degree to the depletion of soils as reflected by their chemical characteristics. Remedial measures can effect restoration in varying degree, according to the nature and extent of the deterioration. What of the highest producing soils? Even though freed as completely as possible

TABLE 12.—*Nitrate nitrogen produced in 4 weeks from native and added nitrogen in soil of Morrow plots.*

	Nitrate-N, lbs. in 2 million of soil from—	
	Soil alone	Soil + $(NH_4)_2SO_4$
	No Treatment	
Continuous corn	43	64
Corn, oats, (sweet clover)	—	96
Corn. oats. red clover	75	160
	Manure, Limestone, Phosphate	
Continuous corn	71	193
Corn, oats (sweet clover)	—	300
Corn. oats. red clover	91	289

of fertility handicaps of the soil itself and located in a favorable climatic environment, average yields are only from one-half to three-fourths as high as the yields which it seems should be expected, and which, as on the poor soils, are attained occasionally. This problem is not solved, but a step in advance is being taken. When the capacity of the soil to supply the crop is stepped up beyond the capacity of the crop to utilize it, the time is ripe for the soils men to team up with the workers in crop production and plant breeding in the interests of harmonizing the crop and the soil.

The generous cooperation among the workers of the corn belt and other states and the U. S. Dept. of Agriculture is becoming abundantly evident and such a cooperation—one that gives each the benefit of the experience of all, and yet leaves to each unit its freedom of initiative—will go far toward solving the problems of conserving the soil for the support of mankind.

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SOIL DETERIORATION AND SOIL CONSERVATION FROM THE VIEWPOINT OF SOIL MICROBIOLOGY[1]

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STUDIES of the fundamental problems underlying the processes of soil deterioration and soil conservation must be broad in scope. They must include not only those processes which result in the removal of a part of the soil by water and by wind erosion, but must also embrace all processes which lead to a reduction in the fertility of the soil, whether initiated by man or brought about by natural forces. As a result of soil treatment, changes are brought about not only in the physical and chemical soil conditions, but also in its microbiological state. The soil microbiological population is sensitive to changes. Its response to various soil treatments is expressed not only by changes in numbers of micro-organisms, but also by changes of the nature of the various specific groups of organisms which are concerned in the different soil processes.

The great abundance of micro-organisms in the soil which gave rise to the conception of the soil as a living system, the great variety of species, and the numerous processes in which they are concerned, all lead to the *a priori* conclusion that they play significant rôles in the changes which take place in the soil. Their activities, and, therefore, soil fertility, must be greatly modified by those processes, initiated by natural agencies and by man, which are recognized under the general term "soil deterioration".

The function of micro-organisms in the numerous soil processes is not always recognized and is usually taken for granted. Unfortunately, the presence of micro-organisms in a natural medium is not always sufficient indication that these organisms are concerned in fundamental processes, that the undesirable forms are absent, and that the desirable forms are present in sufficient abundance to bring about the particular change in an economic manner. In order to establish the rôle of micro-organisms in the processes of soil formation and soil destruction, it is essential to recognize certain criteria for measuring their activities. Any attempt to consider all of the specific organisms present in different soils and the numerous transformations that they bring about would be too confusing, not only for the layman but for an expert as well, even assuming that our present knowledge is sufficient to state definitely which facts are important and which are only incidental.

THE MICROBIOLOGICAL STATE

The problems involved in recognizing the microbiological state of the soil and of distinguishing the microbiological states of different

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soils have puzzled the microbiologist since the beginning of this century. This is well illustrated by the proposal of Chester (2)[3] in 1902 to establish a certain group of criteria for measuring the microbiological condition of the soil, which he designated as "zymotic efficiency". He further suggested that this may be possible when the abundance of bacteria in the soil and the activities of the most important groups are known. By assigning to each soil a certain number of units, on the basis of these determinations, one should be able to make a chart for each soil, as is commonly done in judging animals. Unfortunately, these simple conceptions concerning the complex microscopic population of the soil and their activities were possible only because of the limited knowledge concerning this population. With the rapidly accumulating information of the large numbers of groups of micro-organisms inhabiting the soil, it became recognized that no single criterion is adequate for measuring their numerous activities. This population consisting of innumerable individuals and a host of species, concerned in a variety of soil processes, often conflicting and frequently dovetailing, represents at the present time too complex a condition to lend itself to accurate evaluation by such simple means.

With the advance of our understanding of the microbiological population of the soil and with the introduction of new methods of investigation, it became evident that certain criteria can represent the microbiological state of the soil. The nature of these criteria and the significance to be attached to them have been modified considerably since the time of Chester. The fact has long been recognized (3, 19) that the microbiological condition of the soil, which may be considered as an expression of the quantitative and qualitative nature of its microbiological population, is a resultant of its chemical and physical conditions. Various microbiologists (17) have felt that the results obtained by microbiological methods are more significant than those secured by physical and chemical measurements. The microbial characteristics of the soil are affected by the numerous changes to which the soil is constantly subjected. By recognizing a group of criteria for measuring this microbiological state, one can then proceed to determine the modification of this state by processes which bring about soil deterioration, on the one hand, or soil conservation, on the other.

METHODS FOR MEASURING THE MICROBIOLOGICAL STATE

Attempts to measure the microbiological state of the soil began about 1880, with the original determinations made by Robert Koch of the numbers of bacteria in the soil capable of growing on the gelatin plate. These were soon followed by a number of other investigations, carried out primarily from the point of view of sanitation. Later, the plate methods were replaced or supplemented by more selective procedures, including the Hiltner and Störmer's dilution methods, the Remy-Löhnis solution methods, and the beaker soil methods. More recently another group of methods was introduced, including the

[3]Figures in parenthesis refer to "Literature Cited", p. 121.

Conn-Winogradsky methods of staining the soil, the Cholodny-Rossi attachment slide method, the Christensen Azotobacter method for lime deficiency, the Winogradsky Azotobacter method for phosphorus deficiency, and the Butkevitch-Niklas *Aspergillus niger* method for phosphorus and potassium deficiency. In these last methods various fungi, yeasts, and bacteria are used for the purpose of determining the availability of certain essential plant nutrients in the soil.

The methods for measuring the microbiological state of the soil are thus devised for the purpose of supplying information concerning the nature and activities of the soil population, as well as the practical applications of soil microbiology. It is proposed, however, to discuss here the micro-biological state of the soil from its broadest possible angles. With this in view, the various criteria for measuring this state can be subdivided into three groups, *viz.*, (a) the abundance of micro-organisms in the soil, (b) the presence of specific types of organisms, and (c) the intensity of microbiological activities in different soils.

Whether the abundance of micro-organisms is measured by one of the various plating procedures or whether the staining methods are used, the evidence already made available is sufficient to conclude that various soils show distinct differences in the abundance of bacteria, fungi, protozoa, and other members of their microbiological population. The treatment of the soil was found to have a marked effect upon the abundance of this population (16, 21). Aside from the influence or reaction, organic matter, and fertilizer treatments, numerous other factors modify the abundance of micro-organisms in soil, notably the particular cropping system, cultivation of soil, moisture content, and temperature. Jensen (10), for example, reported recently that a strong positive correlation exists between moisture content and numbers of bacteria in the soil, and a somewhat less pronounced correlation between moisture and fungi. The actinomyces, however, did not seem to be favorably influenced by an increase in moisture, a fact highly significant from the point of view of potato scab control; they were more predominant under conditions of low moisture and high temperature.

Among the specific micro-organisms which are commonly considered as characteristic indicators of certain soil conditions, Azotobacter has received particular attention. Beginning with the work of Lipman and Christensen and ending with that of Gainey and Winogradsky, the abundance in the soil of this characteristic organism was recognized as a definite index of soil fertility. Its absence in distinctly acid and usually infertile soils, its association with a high lime and phosphorus content of the soil, and its ability to increase the concentration of nitrogen, have all combined to emphasize the significance of the occurrence of this organism in the soil. This has been further intensified by the recent studies involving the use of this organism in measuring the amount of available phosphorus in soil.

The soil is frequently analyzed for the presence of a number of other organisms. These may be either beneficial, such as various legume bacteria and sulfur bacteria, or injurious, such as *Act. scabies*, *Rhizoctonia*, different species of *Fusarium*, and numerous other bacteria, fungi, actinomyces, and nematodes. The soil may also contain

certain metabolic products of micro-organisms which have effects upon plant growth. In this connection mention should be made of the recent findings of the accumulation in soil of a bacteriophage which renders the soil unfavorable for the growth of various leguminous plants, notably alfalfa and clover (6). There are other indications in the literature that the presence in the soil of certain organisms is associated with favorable or unfavorable conditions for plant growth; however, this field has been little explored.

The criteria for measuring the activities of micro-organisms in soil can be divided into several distinct groups, as follows:

1. Methods for measuring decomposition of organic matter in soil
   (a) Oxygen consumption
   (b) Carbon dioxide evolution
   (c) Rate of decomposition of the plant and animal residues
   (d) Changes in the chemical nature of the soil organic matter
   (e) Heat changes involved in the transformations
2. Methods for measuring nitrogen availability
   (a) Nitrification of the soil's own nitrogen as well as of added organic and inorganic nitrogenous materials
   (b) Cellulose decomposition, which is controlled by the amount of available nitrogen in soil
3. Methods for measuring the increase in the nitrogen content of the soil
   (a) Non-symbiotic nitrogen fixation
   (b) Growth of legumes and symbiotic nitrogen fixation
4. Use of micro-organisms as indicators for measuring the availability of minerals in soil
   (a) Phosphorus availability
   (b) Potassium availability
   (c) Presence and availability of rare elements in soil

The significance of these processes in soil fertility has been quite definitely established. On the basis of these criteria for measuring the soil biological state, it is now possible to proceed with the determination of the modifications of this state as a result of soil treatments.

MODIFICATION OF THE SOIL BIOLOGICAL STATE

The loss of soil organic matter due to cultivation and erosion may be considered among the most important soil changes which modify the microbiological state. Middleton, Slater, and Byers (15) came to the conclusion that the greatest loss in soil fertility as a result of surface erosion is due to the loss of some of the soil organic matter. That part of the soil which is removed by wind and carried as dust was shown (7, 5) to be much higher in organic matter and in plant nutrients than the soil itself. The drifted soil became impoverished, having on an average 24.5% less organic matter and 28.0% less nitrogen than the virgin soil. In those cases where the drifts contained more organic matter, it was found to be due either to the inclusion of undecomposed residues or to their transfer from a more productive area. The somewhat greater loss of nitrogen than of organic matter was explained by the removal of the finer particles of humus. As a

result of cropping and wind erosion, the organic matter in surface soil was decreased by 18.0%. There was little change in the subsurface soil.

There is no question at the present time that great losses of organic matter result from soil cultivation and from natural causes of wind and water erosion. It has also been generally recognized that in order to prevent soil deterioration by these agencies, the introduction of organic matter is particularly necessary. Soil conservation, from a broad point of view, thus includes the conservation of the organic matter or its introduction into the soil where the supply has been depleted. Whether this is brought about by allowing large areas of land to remain under grass, or by plowing under special crops in the form of green manures and crop residues, or by the actual introduction of organic matter in the form of stable manures, artificial composts, or peats, remains to be determined on the basis of local conditions, nature and value of crops, and other factors.

The favorable effect of organic manures upon the conservation of soil fertility and upon the microbiological state has been established in numerous investigations in many experiment stations in this country and abroad. Without reviewing this extensive literature, attention may be called here to some recent results of the New Jersey Station (1). It was concluded, on the basis of these experiments, that "continuous cropping even under good management and fertilizer treatment tends toward a depletion of the organic matter of the soil thus treated. With heavy applications of farm manure, the content of organic matter is gradually increased over a period of years." When compared with corresponding soils not cropped and fertilized, soils continuously cropped, even if fertilized, showed a gradual loss of organic matter. As pointed out previously, a definite parallelism was found to exist between the organic matter content of the soil and its microbiological state. The latter is largely responsible for keeping this organic matter in a dynamic state, thus resulting in a greater degree of soil fertility. When the soil is plowed and cultivated, a condition will follow which is spoken of as *soil ripeness*, due to the active liberation of carbon dioxide in the decomposition of the soil organic matter by micro-organisms.

Lyon and Wilson (14) observed a close correlation between the nitrate nitrogen accumulation in the soils planted to various cover crops and the loss of total nitrogen. The soils of all the plats planted annually to cover crops lost some nitrogen. In order to mitigate this loss, it was suggested to lay the soil down to grass for a number of years and to introduce into the system those legumes (vetches, etc.) that are most active in fixing nitrogen.

The proper use of green manures, including cover crops, is capable of maintaining the soil organic matter and the soil nitrogen and of improving the physical condition of the soil, enhancing its water-holding capacity, and preventing excessive erosion (12). Green manures are utilized for four distinct purposes, *viz.*, (a) the conservation of the plant nutrients, (b) rendering the nitrogen available for the next crop, (c) addition of organic matter to the soil, and (d) increasing the supply of nitrogen in the soil through nitrogen fixa-

tion. The nitrogen of the green manure is made readily available to the following crop only when its concentration in the plant is above 1.5%. Too rapid nitrate formation may reduce the yield of the subsequent crop by increasing the removal of the nitrate by leaching (4), if there is no growing crop present to utilize this nitrogen.

The favorable effect of stable manures and of composts in keeping up the fertility of the soil has long been recognized and need not be dwelt upon here. It is sufficient to cite in this connection a recent statement of Vandecaveye[4] that "the incorporation in the soil of moderate amounts of plant residues that are fairly high in nitrogen or reinforced with inorganic nitrogen if they are low, not only has the effect of stimulating biological activity and maintaining the productivity of the soil, but also seems to have a very definite effect upon the soil structure which results in increased permeability of the soil and has a tendency to diminish water erosion".

Drying of soil was found to result in a number of changes in the microbiological state. These have been measured (20) by a reduction in the total number of organisms and especially by the gradual elimination to almost complete destruction of certain groups of microorganisms, some of which are causative agents of plant diseases. However, when a dry soil is moistened again, there is a great increase in microbiological activities accompanied by an increase in available nitrate and phosphate. This explains the proverbial heavy crop following a drouth when water, of course, becomes available. The change in the microbiological state of the soil brought about by drying has been compared (20) to that effected by partial sterilization by means of steam and chemicals. While these treatments are primarily used for the destruction of the pathogenic fungi and insects in the soil, they result also in a change in the equilibrium condition of the microbiological state which is usually attained in normal soils.

The survival of pathogenic organisms in soil and their frequent accumulation as a result of the growth of a particular crop constitutes one of the most important problems regarding the microbiological state of the soil. It has been recognized for a long time that in order to eliminate a pathogen completely from the soil or to reduce its abundance or destructiveness, one of the following four procedures must be utilized: (a) Rotation of crops, (b) planting of resistant varieties, (c) elimination of parasite from soil by special treatment, or (d) modification of the soil by changing its reaction or organic matter content so as to render conditions unfavorable for the development of the pathogen. Among the most typical soil organisms which are pathogenic upon higher plants, one may consider the actinomyces causing potato scab. It has been found recently (13) that as a result of crop rotation there is a decrease in the pathogenic forms, both in numbers and in their relative abundance to bacteria, although not in the abundance of actinomyces as a whole. Two hypotheses were suggested to explain this phenomenon, *viz.*, (a) the pathogenic species died out in the absence of a suitable host, or (b) many soil actinomyces have pathogenic tendencies which may actually be lost in the

[4]Personal communication.

absence of the host but which may be regained, first in milder and later in a more virulent form, when the host is provided.

The introduction of beneficial organisms into the soil has not progressed beyond the use of legume cultures. While there is no doubt that certain organisms can be profitably introduced into the soil in many other cases, either because they are absent in certain soil formations or are present in a weakened state, as in the case of various mycorrhiza fungi, the indiscriminate use of all crop inoculants should be condemned. In most cases the modification of the microbiological state will follow the correction of the physical and chemical soil conditions, as following the use of lime on acid soils, of organic matter on depleted soils, proper aeration of poorly drained soils, etc. In the use of sulfur for the correction of alkalinity of the so-called "slick" or black-alkali soils, certain specific bacteria were found to play an important rôle. Whether the introduction of special cultures of bacteria for inoculation purposes is justified or not, the fact remains that the oxidation of the sulfur is brought about largely through the action of these bacteria, the presence of which in soil is highly essential.

Another important soil phenomenon may be classed under the group of processes leading to soil deterioration, namely, the formation of "sick" or "exhausted" soils. In many cases, this is due to the accumulation of fungi, bacteria, and protozoa, parasitic either upon the higher plants or upon the normal microbiological population. In other cases, it is due to the formation of toxic substances, the nature of which is not fully established, which are injurious to plant growth, in one way or another. Some of these deficiencies can be corrected by treatment of soil with steam or certain chemicals (partial sterilization), others by the introduction of specific mineral elements not commonly employed in fertilizer mixtures, such as copper, manganese, and zinc. One is dealing here with a group of important soil relationships, the nature of which is still incompletely understood, although considerable knowledge has already accumulated and various methods (palliative to be true) have been developed for correcting the deficiencies. Attention may also be called here to the recent work of Demolon (6) on the phenomenon of "soil fatigue" caused by the accumulation of bacteriophage in old alfalfa soils. This results in the destruction of the specific bacteria concerned in the formation of nodules, leading to reduced nitrogen-fixation. The plants behave under these conditions as non-legumes. Different plants and different varieties of *B. radicicola* are not sensitive alike to the bacteriophage, which suggests methods for overcoming this soil condition.

SOIL CONSERVATION AND THE SOIL BIOLOGICAL STATE

The major problems of soil conservation from a microbiological point of view are thus found to be closely related to the prevention of losses in fertility as a result of soil cultivation, of wind and water erosion, and to the use of certain specific cropping systems. The losses in fertility as a result of cultivation are enormous. Jenny (11) calculated that as a result of 60 years of cultivation these may amount to one-third of the total fertility in the case of non-eroded land. Dur-

ing the earlier periods of cultivation, the losses are much greater than during the later periods. After several decades, however, the nitrogen of the soil tends to reach a more or less stable level, this level being much higher for good systems of soil management than for poor ones. Similar results have been obtained by Gainey and his associates (8) for the semi-arid soils of western Kansas where large losses of nitrogen were shown to take place under certain conditions. When the nitrogen content of the soil fell to approximately 0.1%, the factors (microbiological?) responsible for additions of nitrogen to the soil were able to counterbalance those tending to cause the removal of the nitrogen, thereby establishing an equilibrium at this level. Sievers and Holz (18) also noted large losses of nitrogen as a result of cultivation. They stated, however, that, "it is possible that, in the extremely arid regions where nitrogen losses through cropping are light, there may be sufficient free fixation of nitrogen to provide for the maintenance or even increase of the soil organic matter. In the more humid portion of the area, the loss of nitrogen through cropping is heavier and free fixation cannot be relied upon to maintain the supply."

According to Hutton (9), the rapid decrease in the organic matter content of the soil due to continued cultivation and with a return of little or no organic matter, favors decoherence of the particles in the soil granules. This was considered as an important factor in producing conditions favorable for soil drifting. At a conservative estimate it was calculated that during the 50 years when these soils have been under cultivation as much organic matter has disappeared as has been accumulated during the previous 5,000 years. "This long-time depletion of organic matter, together with the prolonged drought which destroyed or prevented the growth of a vegetative covering and made overgrazing a necessity, together with the fact that the moisture films on the soil particles have been so thin for many months, all have favored the movement of the soil by the wind."

In addition to their contribution to the formation and decomposition of soil organic matter and to the transformation of nitrogen and other nutrient elements in the soil, numerous micro-organisms actually exert a binding effect upon the soil, thus modifying soil structure. This is true especially of the free-living and mycorrhizal fungi, as well as of the slime-producing bacteria. It is sufficient to cite, in this connection, the following illustrations. Some years ago there was sent to the laboratory of the state chemist of New Jersey a large clump of sandy material from the Lakewood area. It looked like a mass of asbestos, the fine and coarse sand particles being held together so firmly that some force had to be exercised in order to separate them. The chemist could find no explanation for this phenomenon and finally appealed to the microbiologist, who found that *Zygorhynchus*, a member of the *Mucorales*, with its long, non-septated mycelium was responsible for the formation. This rôle of fungi is of special significance in the case of forest soils, where they act as soil binders, especially in the case of the surface layers. Prof. Hudig[6] of

[6]Personal communication.

Holland has shown that when a surface layer of peat is plowed under with the underlying mineral portion of the soil, the organic and inorganic soil constituents remain as independent systems for a considerable period of time. However, when fresh, readily decomposing organic residues are added, the extensive microbial synthesis produces a homogeneous soil with the organic and inorganic constituents bound together. This function of micro-organisms in binding the soil particles, thus improving the soil structure, is not yet fully recognized.

SUMMARY

The soil is not a dead, lifeless mass of rock constituents, but is in a true sense a living system. Numerous groups of micro-organisms inhabit the soil to the extent of hundreds of millions of individual cells in a single gram of soil. These organisms are responsible for most of the chemical changes which are taking place in the soil, many of these changes liberating the nutrient elements from the soil materials and making them available for plant growth. Changes in the physical and chemical soil conditions, as a result of cultivation and different cropping systems, are accompanied by corresponding changes in the numbers and activities of these micro-organisms. The microbiological state of the soil can rightfully be considered as an index of the fertility condition of the soil.

The problems of water and wind erosion of the soil, as well as soil deterioration due to improper systems of cultivation, are closely associated with the problem of soil organic matter. A decrease in the organic matter content of the soil accompanies soil deterioration and is in itself a cause for further deterioration of the soil, while an increase of the content of organic matter and nitrogen is a symbol of soil improvement. Micro-organisms are closely associated both with the formation and with the destruction of the organic matter in the soil, and with an increase or a decrease of the available nitrogen. Any systems of permanent soil improvement or soil conservation must, therefore, consider the influence of soil treatment upon the activities of the soil-inhabiting micro-organisms, as well as the methods of utilizing their activities in order to bring about a permanent system of agriculture. Furthermore, soil erosion results in the loss of the "active" or "living" surface layer of the soil, leaving the "dead" subsoil. The latter, because of lack of aeration and lack of sufficient nutrients, limits the growth of the important micro-organisms. The soil may also become infested with pathogenic organisms as a result of certain systems of cropping, thus leading to a condition which characterizes "sick" or "exhausted" soils. This condition can be prevented or corrected by proper systems of crop rotation and soil improvement. Soil conservation must keep a proper balance of the microbiological population of the soil and a proper state of microbiological efficiency.

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PHOTOPERIODISM, A FACTOR IN DETERMING THE MANURIAL EFFICIENCY AND DISTRIBUTION OF *CROTALARIA JUNCEA*[1]

B. N. Singh, S. N. Singh, and M. B. Srivastava[2]

IN a previous contribution (5)[3] stress was laid on the stage of maturity of *Crotalaria juncea* that would add to the soil the maximum quantity of fertilizing constituents when the plant was plowed under. Since the problem of green manuring is of worldwide interest, it was thought desirable to study the possibilities of the introduction of crotalaria as a green manure crop in widely separated parts of the world, thus necessitating a study of the marked differences engendered in the plant by altered environmental conditions. The living organism displays so many simultaneous processes, however, that in order to study the influence of a given factor upon the growth of the plant, it is necessary to vary that factor, keeping all others constant.

In the study reported here, an effort has been made to study the influence upon the manurial value of *Crotalaria juncea* of different exposures to light. The data are also analyzed in the light of Blackman's law of limiting factors (2) with a view to studying the light requirements of crotalaria and its energy economizing power. Finally, suggestions based on the experimental findings have been advanced with regard to the adaptability of the plant in long-day countries for green-manuring purposes and the possibilities of its cultivation in mixtures with other plants.

METHODS AND MATERIAL

A uniform population of potted plants was divided into eight experimental sets. Each set of plants was then subjected to a definite period of illumination. The general procedure was the same as discussed in the previous contribution (5). The hours of illuminations were as follows:

Exposure	Time
Subnormal	
1 hour	12 noon to 1 p.m.
3 hours	11 a.m. to 2 p.m.
6 hours	10 a.m. to 4 p.m.
8 hours	9 a.m. to 5 p.m.
Normal	
11 hours	7 a.m. to 6 p.m.
Supra-normal	
16 hours	7 a.m. to 11 p.m.
20 hours	7 a.m. to 3 a.m.
24 hours	7 a.m. to 7 a.m.

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication October 19, 1936.

[2]Director of the Institute and Research Scholars, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 133.

Plants exposed for 11 hours or less received natural light for illumination, after which they were covered with light-proof boxes having adequate provision for aeration by means of valve-ventilators. For supplying extra hours of illumination recourse was had to high intensity, 1,000-watt, gas-filled tungsten filament lamps.

EXPERIMENTAL FINDINGS

A survey of the data (Table 1) clearly indicates that with an increase in light duration, a positive change takes place in the general characters of crotalaria, *viz.*, in height of the plant, number of leaves, leaf area, root length, number and weight of root nodules, and length and yield of fiber, with a gradual delay in flowering which is completely suppressed under continued illumination. The critical light period for this plant apparently lies between 16 and 20 hours per day.

The length of the photoperiod considerably affected the size and the distribution of root nodules. During the early stage of development in all cases, the nodules were similarly distributed, most of them appearing at the crown of the plant while some were found along the tap root as well. As the plant advanced in age, the number and size of the nodules increased with an increase in length of day. In plants exposed to a short day, the nodule development was very much checked. The highest figures both with regard to the number and the weight of the root nodules per plant were obtained with 20 hours of illumination at the initiation of the reproductive stage.

The area of the leaves per plant also increased with an increase in length of day, reaching a maximum under continued illumination, which is nearly double normal exposure. In spite of a marked increase in leaf area, products of the photosynthesis were found to undergo a reduction under continued illumination, due probably to solarization.

MANURIAL EFFICIENCY

The relative length of day seemed to influence the manurial efficiency of the crop to a considerable extent. The data presented in Table 1 show the amount of the various fertilizing constituents per plant as well as per acre calculated on seed rate basis only at the beginning of the flowering period—the stage at which the highest contribution is made by this plant to the soil, except for those plants exposed to continuous illumination. Plants exposed to 1 and 3 hours of light, on account of their short life and the slight contribution they may make to the soil, have not been taken into consideration. (See Fig. 1.)

On reviewing the data it is observed that all of the fertilizing constituents increased with an increase in the length of day, the greatest increase being attained in all the cases with 20 hours of exposure, except for potash and calcium which attained their maximum values under continued illumination. The phenomenon of solarization with regard to the other constituents is quite apparent under 24 hours' exposure. The variation in potash and calcium cannot be explained with any degree of certainty at present.

It is obvious, however, that the best results with regard to the manurial efficiency of this crop are to be had under 20 hours' exposure.

The tonnage of plant material to be incorporated into the soil reached a maximum with 24 hours' exposure. On studying the general characteristics of the plant, however, it will be observed that in addition to the large amount of the photosynthetic products ob-

FIG. 1.—*Crotalaria juncea* grown with various daily light periods ranging from 1 hour to continuous light, as indicated by the numbers on the containers.

tained with 20 hours' illumination, these plants also produced thick, flexible stems, dense foliage, approximately the highest number of leaves per plant, and the best root and root nodule development which are of no small importance, in contrast to the hard, woody nature of the roughage produced under continued exposure.

TABLE 1.—*Effect of exposure to light for varying lengths of*

Light duration in hours

General Characters			
Av. height, cm	39.0±0.12	60.0±0.23	102.0±1.10
Av. No. leaves per plant	6.0±6.063	12.0±0.032	46.0±0.041
Av. leaf area per plant, sq. cm	26.0±0.118	54.0±0.13	506.0±0.342
Av. root length, cm	13.1±0.012	16.4±0.021	26.2±0.183
Av. No. root-nodules per plant	5.0±0.002	9.0±0.018	26.0±0.032
Dry weight root nodules per plant, grams	0.01	0.20	1.11
Age at flowering, days	——	——	31–38
Av. No. flower heads per plant	——	——	29.0±0.138
Fiber length, cm	30.0±0.128	58.0±0.131	95.0±0.628
Yield of fiber per acre, lbs	26.1±0.123	68.3±0.132	250.4±4.11
Fertilizing Constituents*			
Dry weight per plant, grams	——	——	2.90
Total carbohydrates, %	——	——	18.32
Total carbohydrates per plant, grams	——	——	0.6412
Total nitrogen, %	——	——	4.16
Total nitrogen per plant, grams	——	——	0.1382
Phosphorus, %	——	——	0.31
Phosphorus per plant, grams	——	——	0.0108
Potash, %	——	——	0.94
Potash per plant, grams	——	——	0.0332
Calcium, %	——	——	2.69
Calcium per plant, grams	——	——	0.0941
Fertilizing Constituents in Pounds per Acre†			
Total roughage	——	——	754.0
Total carbohydrates	——	——	166.68
Total nitrogen	——	——	35.90
Phosphorus	——	——	2.80
Potash	——	——	8.60
Calcium	——	——	24.40

*Calculated in percentage and in grams per plant on dry weight basis.
†Calculated on seed rate basis.

LIGHT REQUIREMENTS

On plotting the values for total carbohydrates and nitrogen against duration of light exposure (Figs. 2 to 5), it is observed that in the case of the young plants the values are very low under all the exposures. As the age of the plant advances an ascending phase in the curves is noted. During the latter half of the life cycle, an increase in the carbohydrate and nitrogen content parallels an increase in length of day. In general, the curves are smooth, as observed by Singh and Lal (4), with no sharp break as observed by Blackman (2). During the early stage of plant growth, the nature of carbon and nitrogen assimilation is quite characteristic. To start with there is a rise in both with an increase in the light duration followed by a leveling out phase which terminates in an ascending phase. In some cases even more than one horizontal phase is noticed. It seems that at these stages some of the factors individually or collectively might

time upon various characteristics of Crotalaria juncea.

Light duration in hours				
8	11	16	20	24
General Characters				
119.0±1.20	144.0±1.34	177.0±1.61	180.0±1.19	189.0±1.63
55.0±0.123	68.0±0.118	71.0±0.123	93.0±0.132	94.0±0.151
660.0±0.932	884.0±1.32	1,136.0±2.38	1,498.0±3.89	1,504.0±4.32
30.3±0.01	36.1±0.321	40.5±0.181	42.1±1.21	41.2±1.01
34.0±0.62	56.0±0.609	76.0±0.432	109.0±1.13	101.0±0.892
1.61	2.01	2.31	2.80	2.40
38–45	45–52	59–66	73–80	——
36.0±0.023	48.0±0.181	64.0±0.296	39.0±0.23	——
110.4±1.12	138.1±1.13	170.4±1.60	173.8±1.30	180.7±1.10
453.6±5.11	650 3±5.62	1,220.3±8.32	1,400.0±8.92	1,460.0±9.62
Fertilizing Constituents*				
3.34	4.30	5.82	7.89	10.01
26.38	32.66	32.74	32.74	22.11
1.0815	1.4473	1.9053	2.3977	2.3656
5.25	7.00	8.22	9.54	7.23
0.2152	0.3430	0.5058	0.7353	0.7230
0.34	0.31	0.43	0.45	0.31
0.0123	0.0153	0.0250	0 0340	0.0310
1.53	1.95	2.11	2.93	3.41
0.0511	0.0906	0.1329	0.2311	0.3420
3.43	2.58	3.98	4.01	4.65
0.1488	0.1626	0.2316	0.3054	0.4310
Fertilizing Constituents in Pounds per Acre†				
868.0	1,118.0	1,513.2	2,051.4	2,602.6
307.40	378.75	495.30	613.80	487.25
55.90	89.10	131.40	191.40	187.98
3.19	3.90	6.40	8.83	8.06
13.20	23.50	34.50	60.80	88.92
38.60	42.20	60.20	79.30	112.06

be exercising their influence in retarding the plant processes even with an increase in length of day. The external factors being at an optimum, the sudden change may be accounted for by the immature development of the chloroplast area, the seat of photosynthetic activity, because such behavior is never noticed in a mature plant and the curves rise sharply until the 20-hour illumination period is reached. With further increase in length of day, a diversity in the results is observed in some cases, due probably to solarization.

DISCUSSION

From the foregoing observations it is apparent that the duration of illumination is one of the "master factors" which play a prominent rôle in determining the growth efficiency of *Crotalaria juncea*. According to Adams (1), rate of growth is primarily dependent upon the amount of assimilates formed. Every individual needs a specific

amount of assimilate for its development; it matters less how the light is distributed throughout the day. Interesting results obtained by Schroeder, Puriewitsch, and Willastatter and Stoll and cited by Lundegardh (3), on the energy relations of plants, have shown that whatever the intensity of the source of the illumination may be and however it may be distributed, only a fraction of the available illum-

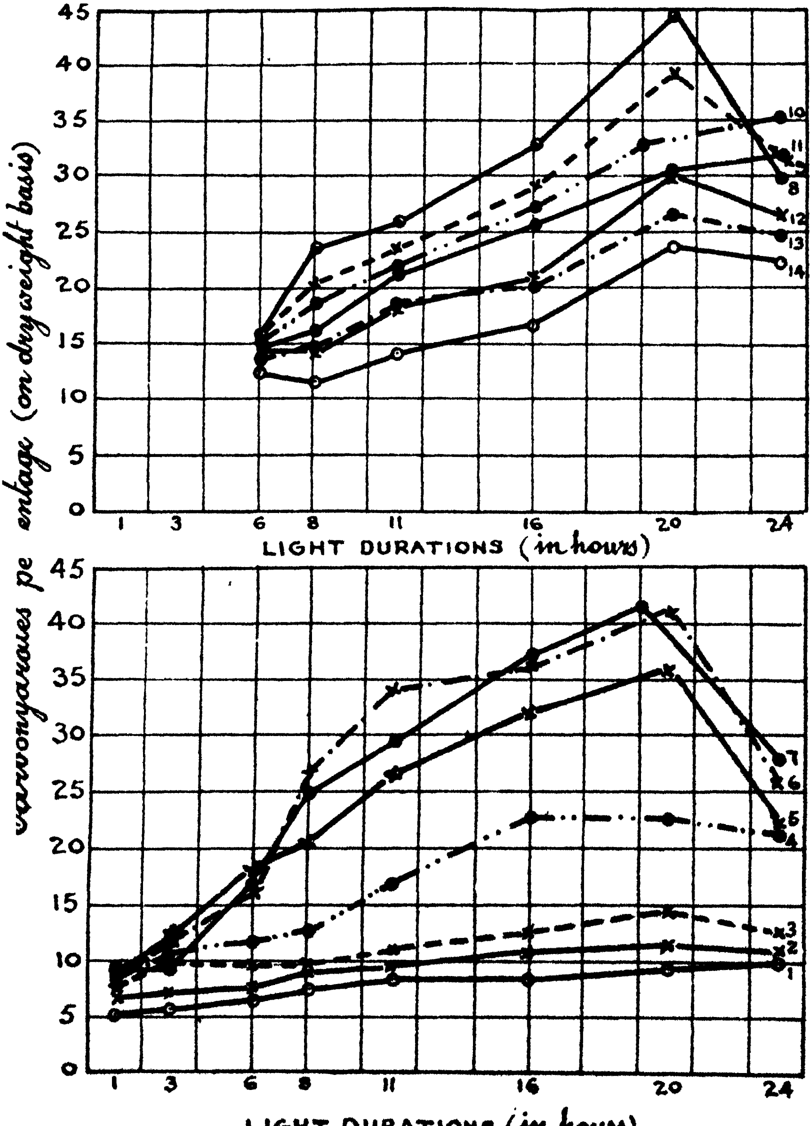

FIG. 2.—Percentage of carbohydrates in *Crotalaria juncea* in relation to length of day at 14 successive stages, beginning 10 days after germination and continuing for 101 days with intervals of 7 days.

ination is utilized by the plant in its various functional activities—a fact fully substantiated by Weisner's conception of light minimum. He studied the light intensity falling upon the top leaves of fully illuminated plants and of that falling upon the shaded leaves of the

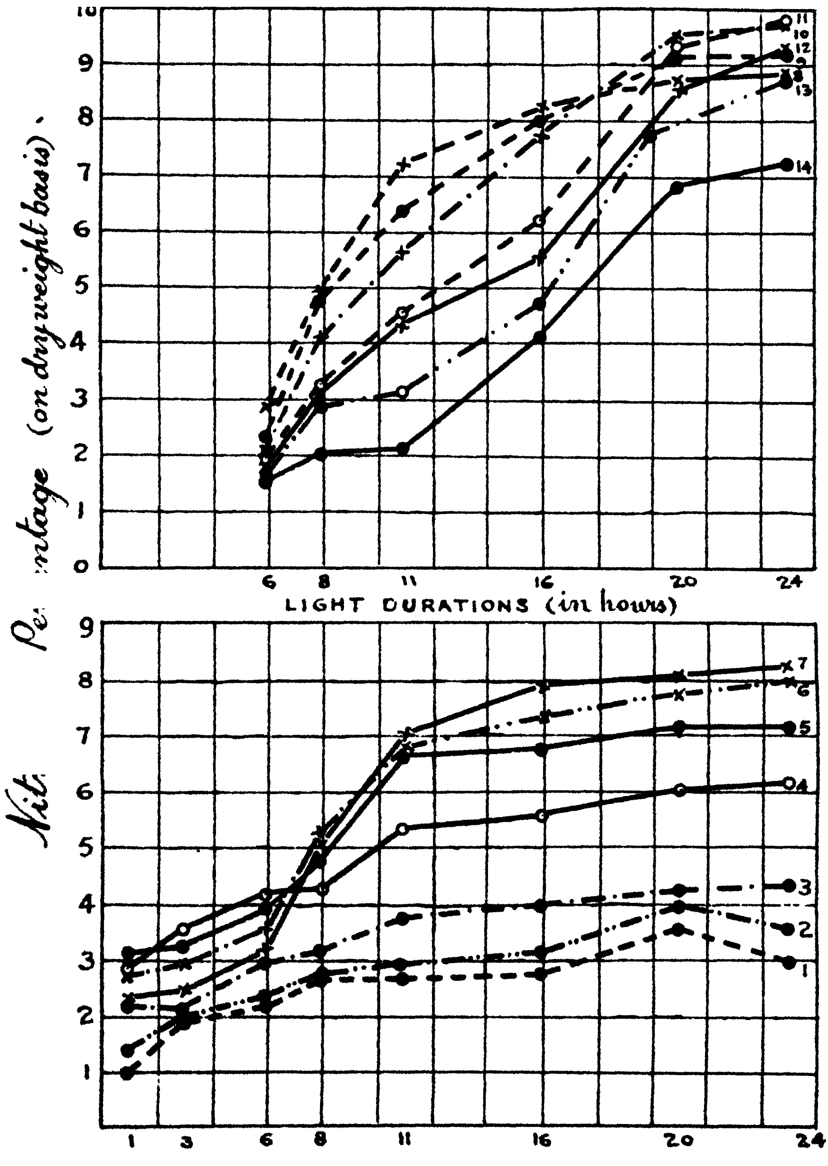

FIG. 3.—Percentage of total nitrogen in *Crotalaria juncea* in relation to length of day at 14 successive stages, beginning 10 days after germination and continuing for 101 days with intervals of 7 days.

same plants and found that the intensity in the latter case was a fraction of the former and concluded that there is a minimum limit of light intensity which can produce normally functioning plants. For every species of plants growing under constant conditions, there seems to be a relative light minimum of a fairly constant value under all other constant conditions of soil and atmosphere.

Crotalaria is a tropical legume, but from the results of these in-

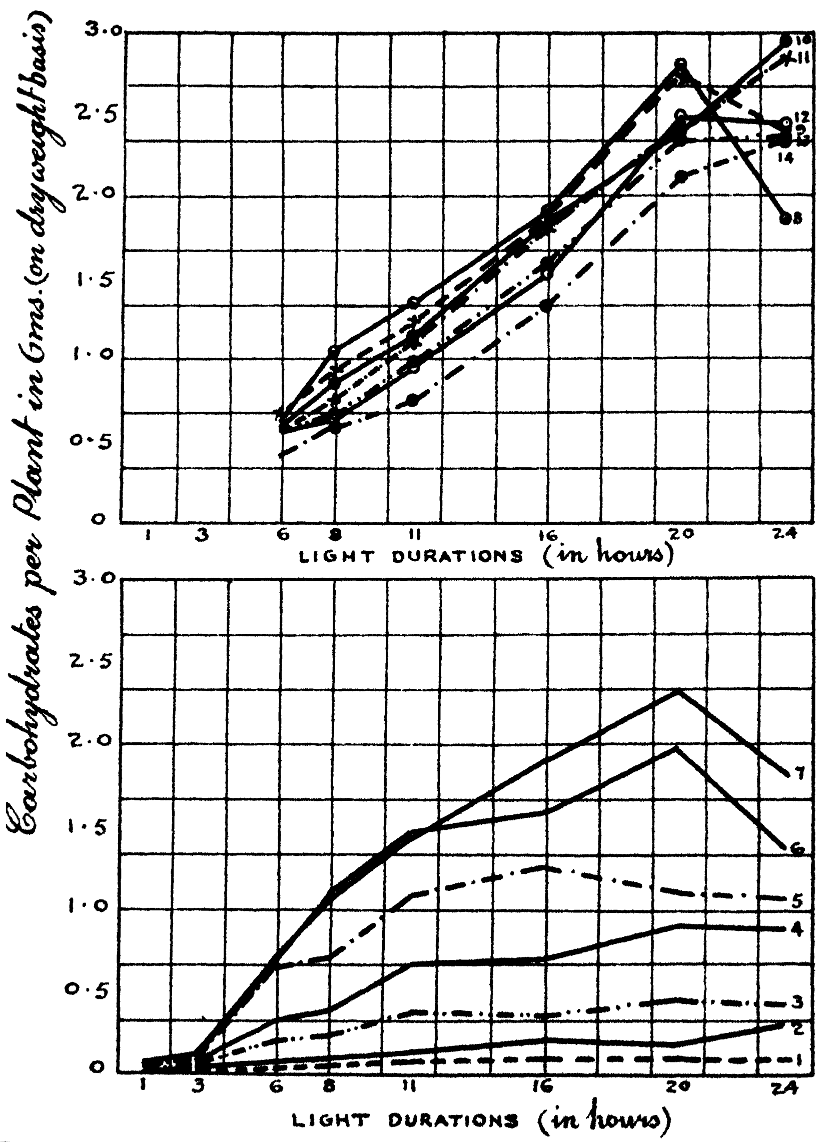

FIG. 4.—Carbohydrates in grams per plant of *Crotalaria juncea* in relation to length of day at 14 successive stages, beginning 10 days after germination and continuing for 101 days with intervals of 7 days.

vestigations it is apparent that from the standpoint of vegetative growth and the reproductive phases, it grows best under illumination from 6 to 20 hours and 11 to 16 hours, respectively. On this basis its introduction as a green manuring plant in regions with long periods of

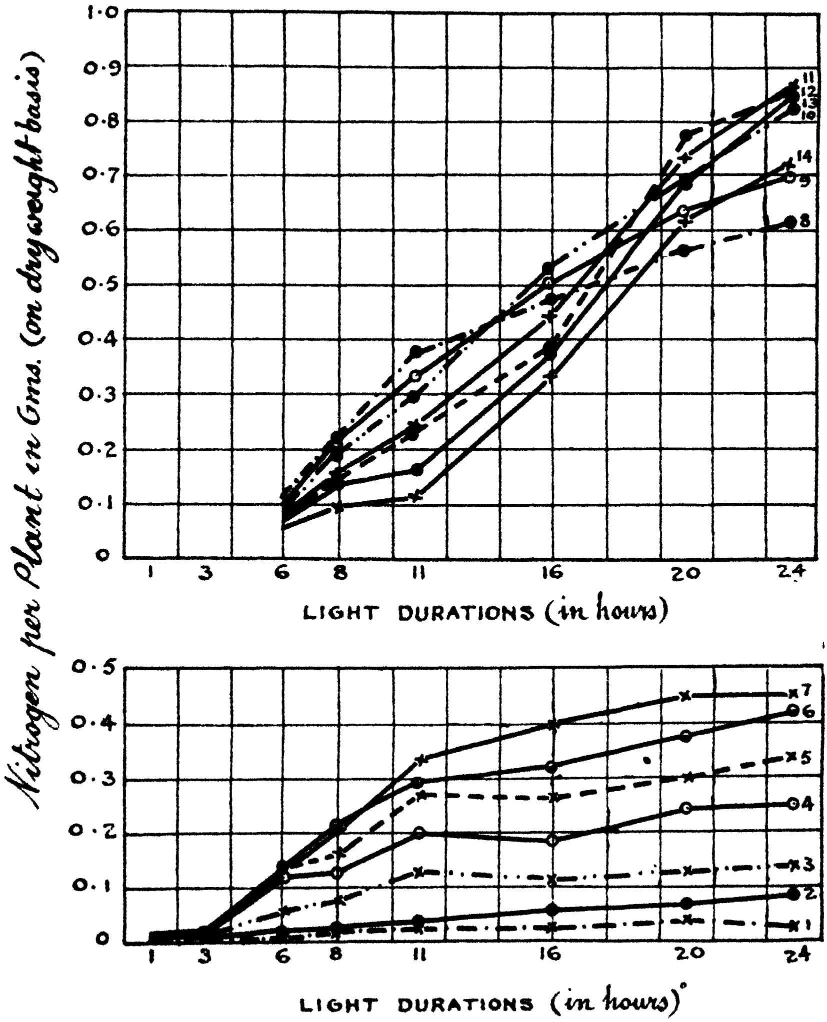

FIG. 5.—Total nitrogen in grams per plant of *Crotalaria juncea* in relation to length of day at 14 successive stages, beginning 10 days after germination and continuing for 101 days with intervals of 7 days.

daylight is indicated, although it may involve a number of problems both edaphic and climatic. Crôtalaria grows normally in a sandy loam soil and under moist, hot conditions with an average rainfall of approximately 32 inches. Light intensity may play an important rôle, but a study of the relative light minimum for this plant in different latitudes may very well overcome this difficulty. The

composition of the illumination may also have some effect. In the present investigation the supra-normal illumination represented a mixture of natural light and artificial electric light. If this mixed illumination be calculated in terms of pure sunlight, the optimal duration may probably be shortened.

A study of the light requirements of Crotalaria indicates that its entire life cycle may be divided into two parts. In the first stage the light requirements are low and the plant is unable to utilize all of the energy falling upon it because after a certain period further increase in the duration of illumination does not result in an appreciable increase in the accumulation of the protoplasmic ingredients. In the second stage the light requirements are considerably higher and with an increase in the daily illumination, photosynthesis increases in regular sequence up to 20 hours in some cases and up to 24 hours in other cases.

It may be inferred from this that *Crotalaria juncea* may be grown successfully in regions having 16 to 20 hours of sunshine and under such conditions will prove to be valuable as a green manuring crop, provided the edaphic and climatic factors which condition the relative light minimum of the plant do not interfere. Furthermore, since the light requirements of this crop are low during the first half of its life cycle and since the plant cannot utilize all of the energy at its disposal as it does later on, it may be sown in mixtures with early-maturing crops. A study of this phase of the problem is now in progress.

SUMMARY AND CONCLUSIONS

Investigations were conducted to study various plant responses in *Crotalaria juncea* to different exposures to light at different stages of development. The efficiency of the plant for green manuring was also determined on the basis of the fertilizing constituents that might be incorporated into the soil at different stages of growth.

With an increase in the length of time of light exposure, an increase in the physical characters of the plant was observed, *viz.*, height of the plant, number of leaves per plant, leaf area, root length, number and weight of root nodules, and length and yield of fiber. Some of these characters attained their maximum development under continued illumination, while others required only 20 hours' exposure, longer exposure resulting in solarization.

The critical light period for Crotalaria apparently falls within the zone of a 16- to 20-hour day. Beyond this range flowering was completely suppressed and the plant remained purely vegetative.

Manurial efficiency increased with an increase in the length of the photoperiod, attaining its highest value under 20 hours' exposure.

During the early half of its life cycle, Crotalaria seems to require less light and plants growing under longer exposures are unable to economize the entire energy falling upon them. With further advance in age, however, the light requirements increase. Thus on the basis of these observations, it may be concluded that a photoperiod of 16 to 20 hours considerably increases the manurial efficiency of this crop. If other environmental factors do not interfere, it may be concluded

that Crotalaria can be successfully introduced as a green manure crop into regions with long periods of daylight and that it may be grown to advantage in mixtures of early-maturing crops.

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FORMAMIDE AS A NITROGENOUS FERTILIZER[1]

C. J. Rehling and J. R. Taylor, Jr[2]

As a result of recent trends toward more concentrated fertilizer materials, the synthetic nitrogen industries have manufactured several substances which have proved to be of great economical and practical value, especially in the mixed fertilizer trade. Important among these materials are anhydrous ammonia and urea-ammonia liquor. These products, important in the manufacture of base goods, make possible the economical formulation of mixed fertilizers of low equivalent acidity (3)[3]. Certain difficulties are involved, however, in the use of ammonia in concentrated, mixed fertilizers. Keenan (7) found that the introduction of more than 2 or 3% of nitrogen as ammonia in superphosphate caused reversion of the available phosphate. In such mixes, urea has been found to be stable; it causes no reversion and can be used in producing a highly concentrated product. Another synthetic material, namely, formamide, has been shown to behave like urea in that it produces no reversion.

Formamide, being a good solvent for urea, has been proposed as a constituent of a modified urea-ammonia liquor. When a urea-ammonia liquor containing formamide is added to a superphosphate, the formamide undergoes hydrolysis to yield ammonium formate which is stable in the mix and causes no reversion of available phosphates.

From solution studies, Ciamician and Ravenna (1, 2) reported formamide as being toxic to plants, but no attempt was made to study its effect in a soil medium.

The object of this investigation was to evaluate formamide as a nitrogenous fertilizer material from the standpoint of its efficiency in promoting plant growth under various conditions such as would be met with in general fertilizer practice. It also included a study of the course and rate of decomposition of formamide and certain related compounds together with an attempt to determine any possible limitations on their use.

AMMONIFICATION-NITRIFICATION STUDIES

The formation of ammonia in the soil from a material containing ammonia nitrogen is usually regarded as a primary factor in evaluating it as a fertilizer material. The simpler organic nitrogen compounds, such as the amides of which urea is perhaps the most widely used, must undergo only hydrolysis reactions to yield ammonia and their ammonification may therefore be expected to be rather rapid.

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[3]Figures in parenthesis refer to "Literature Cited", p. 143.

Since this hydrolysis is assisted by bacteria and since the ensuing nitrification reactions are dependent upon micro-organisms, the rates of ammonification and nitrification should reflect any toxicity for these organisms.

It was the purpose of this study to determine the ammonification and nitrification changes of urea, formamide, and ammonium formate in the first five soils described in Table 1.

TABLE 1.—*Soils used in the investigation.*

No.	Soil type	Geologic classification	Reaction pH	Comments
1	Norfolk sandy loam	Marine Coastal Plain	6.05	From a limed plat on Experiment Field, Ala.
2	Norfolk sand	Marine Coastal Plain	5.30	Very low fertility, Ala.
3	Cecil clay loam	Residual Piedmont Plateau	5.20	Ala.
4	Decatur clay loam	Residual Limestone Valley	5.75	Good fertility, Ala.
5	Monongahela fine sandy loam	River Flood Plain	5.30	Medium fertility, W. Va.
6	DeKalb silt loam I	Residual Appalachian Mountains	5.75	W. Va.
7	DeKalb silt loam II	Residual Appalachian Mountains	4.75	W. Va.
8	Bridgehampton fine sandy loam	Glacial	5.0	R. I.

METHODS

Soil cultures were prepared in tumblers and a set used for each analysis. Potassium acid phosphate was added to all cultures at the rate of 400 pounds per acre and each of the three nitrogenous substances at the equivalent rates of 100, 200, and 400 pounds of nitrogen per acre. After adjusting to optimum moisture content, these cultures were incubated at 27° to 30° C and constant moisture maintained. Analyses for ammonia content were made after 2, 6, 15, and 25 days to determine the time required for complete ammonification of formamide and urea. The nitrate content was determined at weekly intervals and pH readings made at the time of analysis.

The Nessler colorimetric method for the determination of ammonia was found to be worthless in the presence of formamide because this substance completely prevents the formation of the characteristic color. Since distillation methods cause a complete hydrolysis of the formamide, the method of Harper (5) was used and slightly modified so as to maintain about 50% vacuum within the apparatus during 12 hours aeration. Efficiency of ammonia recovery varied with the soil type, being higher in the sandy soils. The ammonia liberated by the hydrolysis of residual formamide during aeration was of significance only in the 2-day period since only a very small amount of formamide was present after this time; the recovered ammonia was simply recorded throughout as the percentage of that added.

Nitrification data were obtained by the phenoldisulfonic acid method from a 1:5 water extract of the soils made with collodion sacks (9). Changes in soil reaction were followed by pH readings made with the glass electrode (8) on a 1:2.5 soil-water suspension.

RESULTS

Data on ammonification, nitrification, and pH change in the Norfolk sandy loam resulting from the addition of various sources of nitrogen are shown in Fig. 1. These data are representative of those obtained for ammonification in the other soils studied. It may be seen that ammonification was generally complete after 2 days with each rate of application. The curves representing the amounts of ammonia present due to ammonification and nitrification of urea and formamide nearly coincide, which indicates a similar behavior of these two substances in the soil. The reactions for ammonification may be written as follows:

$$(NH_2)_2CO + 2H_2O = (NH_4)_2CO_3$$
$$HCONH_2 + H_2O = HCOONH_4$$

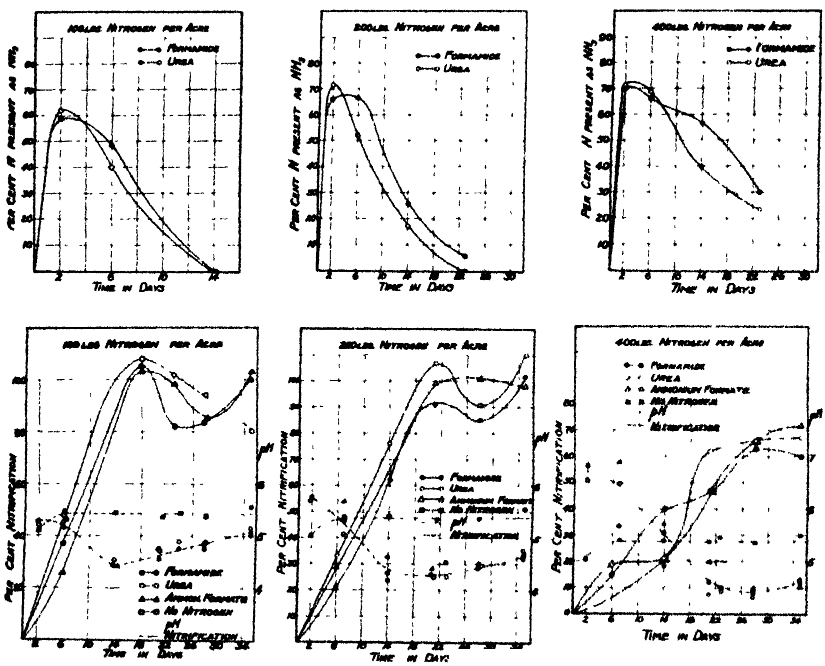

FIG. 1.—Ammonification, nitrification, and pH changes in a Norfolk sandy loam to which different kinds and amounts of nitrogenous fertilizers have been applied.

Nitrification rates varied with the different soils, of course, but the nitrification of the materials in any given soil was found to begin at the same time with each rate of application in that soil and gave very similar curves, except in the case of the Cecil clay loam. It is further to be noted that in the case of this soil no nitrification occurred with any compound, even with urea, after 7 weeks. No measurable lag in nitrification of formamide or ammonium formate was evident and this indicated that no toxic effect to nitrifying bacteria resulted from the addition of these compounds to the soil. Since the

application of 400 pounds of nitrogen per acre is far in excess of that used in mixed fertilizers, and since these would contain comparatively little formamide or ammonium formate if made with a urea-ammonia liquor containing formamide, it seems safe to conclude in the light of the foregoing that formamide presents no difficulties through toxicity to soil bacteria. It behaves almost exactly like urea.

The pH data support these results and conclusions in that the formamide and ammonium formate data so closely agree with the urea data that one general curve may be drawn. Ammonification of the formamide and urea caused a rise to a peak within 2 days and thereafter the lower pH readings resulted from the acidity from nitrification and the amount of increased acidity was generally in accord with the increase in percentage nitrification.

DECOMPOSITION OF FORMATES IN SOIL

The foregoing experiment was solely a study of the behavior and course of the nitrogen contained in urea, formamide, and ammonium formate, while this experiment was essentially a study of the behavior of the carbon of these compounds and certain other formates during their decomposition.

In a complete mixed fertilizer, formamide would be hydrolysed to ammonium formate (4) which, in turn, would enter double decomposition reactions with certain materials present to yield formates of calcium and potassium and for this reason these substances were included in this study.

Since one of the products of organic decomposition in the soil is CO_2, the rate of its production would be a measure of the speed of the process. The reaction with formates may be written $HCOOM + O = MHCO_3$, where M represents one equivalent of any cation. Carbonic acid would be the product of such oxidation with formic acid, while bicarbonates would be produced from the various salts. Oxidation would not be responsible for the CO_2 production from urea since hydrolysis alone yields a carbonate, but formamide must undergo two reactions, namely, hydrolysis and oxidation to yield finally ammonium bicarbonate. Thus, the oxidation reaction in the case of formamide is really confined to that of its hydrolysis product, ammonium formate.

METHODS

Soil cultures were set up and incubated as in the previous experiment. The urea, formamide, and formates were added at the rates equivalent to 500 and 1,000 pounds of CO_2 per acre and mixed with the entire mass of soil. Potassium ammonium acid phosphate was added to all cultures at the rate of 400 pounds per acre.

A recently developed method (4) for the determination of formates in the presence of formamide was suggested as a more desirable method for use in this study than the determination of CO_2 liberated. The method is as follows: The aqueous solution containing not more than 0.05 gram of formic acid or its equivalent is made up to 250 cc in a 500-cc glass-stoppered iodine flask and made neutral to litmus with 10% Na_2CO_3. After adding 90 cc of 0.1 N $KMnO_4$, the solution is allowed to stand for 30 minutes to complete oxidation. About 20 cc of 20% H_2SO_4

is added and followed with 10 cc of 30% KI. The liberated iodine is titrated with 0.1 N thiosulfate using starch as an indicator.

The greater accuracy of this method prompted its adoption, although it could not be used to study the urea decomposition. After all, the ammonification data of the foregoing experiment express the decomposition of urea, since no oxidation is involved. However, the CO_2 production of urea in the soils was studied by an adaptation of the Schollenberger carbonate method (10).

After 2, 4, 6, 10, and 15 days, analyses were made for unchanged formates after mechanically shaking the entire 200-gram culture with 100 cc of 0.5 N KCl and 50 cc of water for 30 minutes and adding about 0.5 gram of alum as a flocculating agent. A 50-cc aliquot of the clear filtrate was titrated by the permanganate method (4) and the loss of added formate recorded as the percentage of the added CO_2. Preliminary trials with this procedure gave favorable results in recovery of added formate, but after a few hours contact with the soil before extraction, low results ensued due to decomposition of the compounds.

In the case of urea, cultures were set up in the same manner, except that 250-cc extraction flasks were used. These were closed with a stopper carrying two outlet tubes adapted for attachment to the carbonate apparatus. By this arrangement the free CO_2, together with any combined as carbonate, was determined and recorded as percentage of that added. Bearing in mind the higher rate of urea application, this method generally gave favorable results which were comparable with results obtained in ammonification studies.

The soil reaction changes were followed by pH readings made with the glass electrode at the time of set up, and after 10- and 20-day intervals.

RESULTS

Typical results on the decomposition of formamide, urea, formic acid, and the formates of potassium, calcium, and ammonium are presented in Fig. 2. Again the group of curves is seen to be similar and will practically coincide. In the soils of better fertility, decomposition had practically reached completion after 2 days with all compounds used at the lower rate of application; at the higher rate, about 75% had decomposed. In the low-fertility Norfolk sand, and especially in the Cecil clay loam, decomposition was not complete until after 4 days, and 6 days were required at the higher rate. It was previously pointed out that these same soils were either slow or lacking in nitrifying power over the period of study.

Soil acidity would be expected to decrease due to decomposition of formic acid and the formates of calcium and potassium with the formation of carbonates. Such was the result as the pH curves clearly indicate. With formamide, urea, and ammonium formate at the higher rate of application, a rise in pH was noted which was then followed by a decline or more acid condition. Ammonification and decomposition followed by nitrification is the probable explanation since in previous experiments nitrification was found to occur. The same soils showed a decided increase in acidity from the 10-day period to the 20-day period, while those soils that gave little or no nitrification showed only a very small increase in acidity. Attention is called the fact that the addition of 1,000 pounds of CO_2 as urea also means the addition of 635 pounds of nitrogen. Ammonification of this urea would appear responsible for the decrease in acidity during the first 10 days.

It may then be concluded that formamide and the formates studied were completely transformed to carbonates in 2 to 4 days in most soils. If formamide were used in mixed fertilizers and these fertilizers were applied to the soil at the usual rates, the amount of formate formed would not be deleterious to crops or soil bacteria.

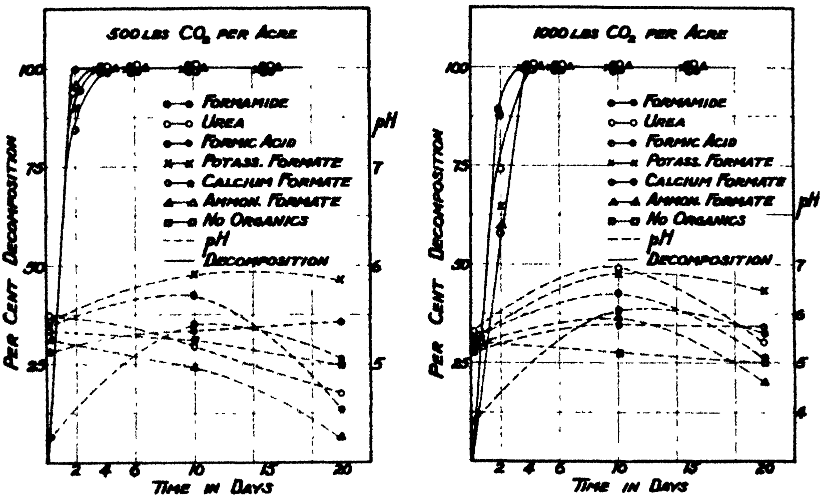

FIG. 2.—Decomposition of various nitrogenous materials and pH changes in Norfolk sandy loam.

GREENHOUSE AND FIELD CROPPING STUDIES

The usual method of evaluating any fertilizer material is cropping the soil which has been fertilized with the material in question. It is under such conditions of common fertilizer practice that results of primary importance may be obtained, since in the end economical crop production determines whether or not the material has any value as a fertilizer.

Consequently, an experiment was conducted in a greenhouse for the purpose of determining the relative efficiency of formamide and its hydrolytic product, ammonium formate, in promoting the growth of different crops on the eight soils listed in Table 1. Furthermore, it seemed desirable to supplement the greenhouse results by extending the study to field plats. The field tests were conducted to determine the difference in growth, if any, resulting from the use of mixed fertilizers made from formamide-containing and formamide-free urea-ammonia liquors, respectively.

METHODS

For the greenhouse studies the air-dry soils were placed in 2-gallon glazed earthenware pots and fertilized at the rate of 1,500 pounds of a 6–8–4 fertilizer per acre. Soil No. 8 was treated somewhat differently as described later. The phosphate was added as superphosphate, potash as potassium chloride, and the sources of nitrogen varied as indicated by the treatments in Table 2 so as to include different combinations such as would result from a urea-ammonia liquor

containing formamide. In all cases, acidity was eliminated through the addition of finely ground dolomite, giving formamide and ammonium formate the same acid value per unit of nitrogen as urea. Magnesium sulfate ($MgSO_4.7H_2O$) was added to soils Nos. 5, 6, and 7 at the rate of 91.5 pounds per acre. The materials were mixed with the entire mass of soil and seeds planted immediately. This procedure was followed before planting each crop, after removing from the soil the roots of the previous crop. All pot treatments were made in duplicate.

Soil No. 8 was fertilized with the equivalent of 2,300 pounds of a 4-14.5-8 fertilizer per acre with certain variations of the nitrogen requirement of this formula as indicated by the treatments given in Table 2. This study also included sodium nitrate as a source of nitrogen, while potash was supplied as K_2SO_4. Buckwheat and rape were grown with the described fertilizer applied before each planting.

Sorghum and sudan grass and two crops of cotton were grown on soils Nos. 1, 2, 3, and 4. The first cotton crop was discarded due to injury from an unavoidable drop in greenhouse temperature.

On soils Nos. 5, 6, and 7 a crop of corn was followed by sudan grass. Due to the high acidity of soil No. 7, the sudan grass seedlings made very poor growth and this series was therefore discarded. A "top dressing" of 45 pounds per acre of nitrogen was applied to the corn crop when the plants were approximately half grown, the same sources of nitrogen being used for each culture as at planting time.

Field tests were conducted on a Norfolk sandy loam in 24 soil bins. The soil in the different bins varied from pH 4.15 to 6.27 due to previous treatments. Two urea-ammonia liquors were used as the sources of nitrogen in these tests. Formamide supplied about one-third of the nitrogen in one of these liquors and the other was free of formamide. A non-acid-forming 6-14.5-4 fertilizer was made from each of these liquors and it was applied at the rate of 1,500 pounds per acre. Alternate bins (1/1,200 acre) with various reactions were fertilized with the two fertilizers and planted to sorghum.

RESULTS

The average results of the greenhouse tests are presented in Table 2. In all of the soils the plants responded greatly to the nitrogenous fertilizers. The data show that the sources of nitrogen which were tested and the combinations used were equally efficient. This was true in the case of each soil. A comparison of the efficiency of urea, formamide, and ammonium formate for cotton seedlings may be made by referring to Fig. 3.

The percentages of the added nitrogen which were recovered by sorghum, cotton, and sudan grass, excluding the nitrogen present in the roots, are shown in Table 3. These data show that the nitrogen recovery varied with the soils and with the crops but did not vary with the sources of nitrogen. Practically the same amount of nitrogen was recovered by the plants from one source of nitrogen as from another.

Results from the field test were grouped according to the acidity of the soil in the bins and are presented in Table 4. It will be seen that the fertilizer containing about one-third of its nitrogen as formamide produced as much sorghum as the fertilizer which contained no formamide, regardless of the soil acidity encountered. This is to

FIG. 3.—Cotton on Norfolk sandy loam fertilized with 1,500 pounds of a 6–8–4 per acre. From left to right, no nitrogen, urea, formamide, and ammonium formate.

TABLE 2.—*The influence of various sources of nitrogen on crop yields from different soils when fertilized with a 6-8-4 at the rate of 1,500 pounds per acre.*

Source of nitrogen	Average dry weight in grams (tops)*					
	Sorghum, soils 1–4, incl.	Cotton, soils 1–4, incl.	Sudan grass, soils 1–6, incl.	Corn, soils 6 and 7	Buckwheat, soil 8†	Rape, soil 8†
None	14.5	1.8	2.9	10.7	14.0	4.0
Urea	41.5	6.0	17.7	49.0	34.0	14.1
Formamide	41.0	6.5	18.3	42.7	33.9	15.6
Ammonium formate	42 7	6.5	17 8	47.4	—	—
Urea 50%; formamide 50%	42.7	6.3	18.0	47.7	—	—
Urea 50%; ammonium formate 50%	41.1	6.6	17.6	51.4	—	—
UAL I; ammonium sulfate‡	42.3	6.5	19.1	49 5	32.2	15.3
UAL II; ammonium sulfate§	42.8	7.1	20.2	46.3	33.4	15.7
UAL III; ammonium sulfate‖	42.9	6.8	21.5	44.6	30.9	13.8
Ammonium sulfate	43.8	7.5	20.9	50.0	—	—

*Soil numbers refer to the soils listed in Table 1.
†The data on soil No 8 were furnished by J. B. Smith, Rhode Island Experiment Station. The cultures were fertilized with a 4-14.5-8 fertilizer at the rate of 2,300 pounds per acre.
‡UAL I refers to urea-ammonia liquor containing no formamide.
§UAL II refers to urea-ammonia liquor containing 0.46% nitrogen as formamide.
‖UAL III refers to urea-ammonia liquor containing 2.18% nitrogen as formamide.

be expected when it is considered that formamide readily forms ammonium formate in the soil which decomposes and nitrifies as rapidly as urea, as was shown by the studies described above.

SUMMARY

Experiments designed to evaluate formamide as a nitrogenous fertilizer are described and the results presented. These studies included the behavior of formamide alone and in mixtures such as

TABLE 3.—*The percentage of nitrogen recovered by sorghum, cotton, and sudan grass when different sources of nitrogen were added to soils.*

Source of nitrogen*	Sorghum†					Cotton†					Sudan grass†			
	Soil 1	Soil 2	Soil 3	Soil 4	Average	Soil 1	Soil 2	Soil 3	Soil 4	Average	Soil 1	Soil 2	Soil 3	Average
None	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Urea	51.5	44.0	81.0	63.0	59.9	33.5	23.0	32.0	44.0	33.1	57.5	48.0	45.5	50.5
Formamide	57.5	44.5	81.0	65.0	62.0	35.0	25.5	31.0	44.0	33.9	62.5	59.0	46.5	56.0
Ammonium fomate	55.5	49.0	78.0	58.5	60.0	35.0	24.0	31.5	46.5	34.2	64.0	52.5	48.0	54.8

*The fertilizer treatments were equivalent to 1,500 pounds of 6-8-4 per acre.
†Analyses were made of the tops only.

TABLE 4.—*Green weight of sorghum, pounds per bin, produced by 1,500 pounds per acre of a 6–14.5–4 fertilizer with and without formamide.*

Bin	pH of soil before planting	Fertilizer containing	
		High formamide*	No formamide†
11	4.15	5.2	0.9
6	4.50	15.3	9.6
7	4.55	16.1	12.1
5	4.57	11.8	14.7
Average	4.44	12.1	9.3
8	5.05	19.8	17.3
9	5.20	21.0	22.1
10	5.20	16.7	17.7
24	5.20	18.1	16.5
1	5.40	15.6	15.5
3	5.40	16.4	20.5
4	5.40	18.0	19.8
2	5.45	11.5	16.2
14	5.47	17.1	20.3
13	5.55	12.2	13.4
21	5.75	24.1	23.6
15	5.80	25.5	27.4
20	5.85	17.2	19.8
22	5.85	21.1	21.7
16	5.90	26.1	24.2
19	6.00	21.2	20.9
Average	5.53	18.8	19.8
12	6.10	24.8	19.9
18	6.10	26.6	21.1
23	6.20	24.0	20.4
17	6.27	20.8	24.9
Average	6.17	24.1	21.5

*Approximately ⅙ of the nitrogen supplied as formamide.
†Nitrogen supplied as ammonium sulfate.

would result in the manufacture of complete fertilizers. The efficiency of these was compared with that of some commonly used nitrogenous materials. A summary of the results follows:

1. Ammonification of formamide was generally complete after 2 days in the soil. Nitrification of formamide and ammonium formate proceeds in the soil in the same manner as that of urea.

2. Formamide, urea, and various formates were found to be decomposed into carbonates in 2 to 6 days in the soil, depending upon soil fertility.

3. Greenhouse and field cropping studies indicated equal efficiency of formamide-containing and formamide-free mixed fertilizers in increasing crop growth.

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THE EFFECTS OF VARIATIONS IN THE YIELDS OF BARLEY UPON THE AMOUNT AND DISTRIBUTION OF THE RESIDUAL SOIL MOISTURE[1]

John P. Conrad[2]

THE residual moisture in the soil, its amount, availability, and vertical distribution at the cessation of the growth of one crop determines in no small degree, especially under conditions of deficient water supply, the moisture available to grow the succeeding crop. Because of the greater amount of transpiration from the greater leaf area, other conditions being the same, a larger crop would use more water than a smaller one from the same sized area. In consequence, the residual moisture under the larger crop would be expected to be less than under the smaller one.

In connection with some other studies to be reported elsewhere, experimental plats with approximately equal initial moisture contents were planted to barley following milo (2).[3] The subsequent treatments given resulted in marked differences in yield at maturity. Increases in yield were induced by the application of nitrate of soda, while decreases were brought about by the application of varying amounts of sucrose. These plats gave an unusually wide variation in production, the weight of total crop of the highest being slightly more than nine times that of the lowest. An excellent opportunity was thus afforded to study the effect of variations in yield upon the amount and especially the vertical distribution of the residual soil moisture.

CULTURE OF THE CROP

Relatively large plats of soil in 1934 were devoted to variety, spacing, and irrigation trials with grain sorghums. After harvest, the whole series of plats was pre-irrigated to make up for the use of water by the Dwarf Yellow (D) milo and Double Dwarf (D.D.) milo crops, particularly in anticipation of a predicted dry year which, however, turned out to be one of slightly more than normal rainfall. Atlas barley was drilled across the former treatments, late in February, with a 6-foot horse-drawn drill, alternate drill holes being plugged to give rows 1 foot apart. As soon as the rows were easily distinguishable by the growth of the young plants, small replicated plats each 6 feet by 18 feet (each plat representing a longitudinal section of the complete 6-foot drill width) were laid out, and on March 22, 1935, sucrose dissolved in water was applied with a sprinkling can to the appropriate plats. Because of rain, the application of the nitrate (likewise dissolved in water and put on with a sprinkling can) was delayed until March 26. At maturity the four center rows of the plat were harvested separately, allowed to dry, weighed for the total crop, threshed, and the grain weighed for the grain yields. The crop yields were computed on an acre basis from the weight of these four rows.

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[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Laboratory facilities for much of this study were kindly furnished by the Division of Irrigation Investigations and Practice. Received for publication November 2, 1936.

[2]Associate Agronomist in the Experiment Station.

[3]Reference by number is to "Literature Cited", p. 152.

The total rainfall at Davis, from July 1, 1934, to Feb. 28, 1935, was 11.43 inches. Rainfall for March was 2.88 inches and for April 4.40 inches, distributed in storms as follows: April 2 to 4, 0.28 inch; April 6 to 8, 2.79 inches; April 14 to 16, 1.17 inches; and April 29 to 30, 0.16 inch. Only a trace fell during May and none in June. Experience would indicate that in a relatively few days after the storm ending April 16, the wave of soil moisture advancing downward would have passed beyond the root zone and left the soil at its field capacity. The series of showers on April 29 and 30 probably had very little effect on the condition of the soil moisture. The rainless seasons from late spring until middle autumn of this section of California provide excellent climatic conditions for studies of this kind. The spring of 1935 was especially favorable as it ended with a fairly heavy rain (April 16) and was followed by almost inconsequential rains thereafter. The late planting necessitated by the heavy rains in January delayed the growth so that most of it was made subsequent to the last rain in the spring.

SOIL MOISTURE TECHNIC

After harvest certain of the plats (in each case not more than one of a replication being taken) were chosen to determine the residual moisture in the soil. Samples were taken on July 10 and 11 with a soil sampling tube, described by Veihmeyer (10), by foot depths down to 7 feet, and then an additional ½ foot to 7½ feet, this being the maximum length of the longer tube used. Two holes were driven for each of the treatments sampled, each hole being located on the center line of the plat 3 feet from its edge. The moisture percentages of the samples were then determined by drying in an oven at 110° C for 48 hours. The dry soil from each sample was broken up in a mortar and then thoroughly mixed. Duplicate moisture equivalent determinations were made on 30-gram (12) sub-samples from each original sample.

Where soil moisture percentages for the same depth from the same plat were somewhat divergent, two additional samplings by foot depths were taken on August 2, 1935. These were from plats 13-S-6, 13-S-7, and 13-S-15. Meanwhile no rainfall occurred and the plats were kept free of weeds. These results were averaged in with the others, as no evidence was disclosed which would justify the discarding of any of the determinations made.

EXPERIMENTAL RESULTS

Table 1 gives the yields of the total crop and of the threshed grain of the specific plats selected for these soil moisture studies, together with the average of the duplicate soil moisture percentages by foot depths determined at the 110° C, and the moisture equivalent determinations made from these same samples. Opposite each foot depth the average moisture percentage of the soil samples is given above, and the average of the moisture equivalent determinations below. It will be observed that the total crop yield varies from slightly above 900 pounds per acre to more than 8,200 pounds per acre. A casual glance at the figures for the soil moisture percentages also discloses a higher amount of residual moisture where the yields are smallest. Determinations on a 1935 fallow plat adjacent with similar crop history previous to 1935 is also included.

TABLE 1.—*Vertical distribution of residual soil moisture percentages together with corresponding moisture equivalents by foot depths under Atlas barley plats which gave widely varying yields.*

Plat No.	14S6	13N7	13N6	13S6	13S7	13S4	13S15	13S17
Crop: 1934 1935	Fallow Barley	D. milo* Barley	D. milo* Barley	D.D. milo* Barley	D.D. milo* Barley	D.D. milo* Barley	D.D. milo* Barley	D.D. milo* Fallow
Material added	—	$NaNO_3$, 600 lbs. per acre	—	—	Sucrose, 2,000 lbs. per acre	Sucrose, 6,000 lbs. per acre	Sucrose, 8,000 lbs. per acre	—
Yield, lbs. per acre: Total	8,221	7,131	4,682	4,426	2,812	2,518	908	—
Grain	4,105	3,697	2,473	2,393	1,483	1,291	406	—
Moisture by foot depths†:								
First, % H_2O	6.09	6.29	6.72	5.91	6.39	7.56	8.51	11.83
M_E	19.42	19.10	19.33	19.25	18.94	19.72	20.13	19.41
Second, % H_2O	8.42	8.68	9.40	9.31	9.98	10.88	13.89	16.61
M_E	18.14	17.54	17.20	18.49	17.48	18.22	19.82	20.03
Third, % H_2O	8.22	8.20	10.95	9.91	10.64	12.67	13.78	14.70
M_E	14.56	15.17	14.84	16.34	15.66	17.51	16.95	16.82
Fourth, % H_2O	8.32	7.78	13.72	9.98	9.14	11.68	15.36	16.32
M_E	16.78	13.86	17.53	14.80	11.72	15.14	17.73	18.74
Fifth, % H_2O	11.66	12.30	14.79	12.69	12.97	14.54	20.27	19.87
M_E	21.60	19.12	18.76	17.53	16.27	17.67	22.24	20.68
Sixth, % H_2O	16.41	16.96	17.88	15.77	16.49	18.95	20.80	21.84
M_E	22.49	20.50	20.20	19.68	18.44	20.57	21.46	21.35
Seventh, % H_2O	19.95	19.44	20.26	17.79	17.52	21.01	22.50	24.20
M_E	21.80	20.70	20.24	18.97	18.44	21.52	20.84	22.85
Eighth‡, H_2O	24.27	24.14	23.42	21.68	19.08	24.80	26.44	28.30
M_E	24.82	23.32	23.04	22.87	19.81	25.52	24.78	25.94

*D = Dwarf Yellow; D.D. = Double Dwarf.
†% H_2O represents percentage of moisture; M_E represents moisture equivalent.
‡From 7.0 to 7.5 feet.

Conrad and Veihmeyer (3) found that soil moisture percentages based on a limited number of soil samples by themselves are apt to be misleading on account of variations in soil texture. By securing figures for the "relative wetness," i. e., the moisture as a percentage of the moisture equivalent, this source of misconception is largely eliminated. Hence, in this study, their example has been followed and relative wetness figures compiled for each foot depth in each of the plats sampled. They also report (3) from figures secured by Veihmeyer and Hendrickson that, "While the different Davis soils tested did not agree exactly with each other, the ratio of the residual moisture at permanent wilting to the moisture equivalent averaged about 50%." A relative wetness of 50% then may be assumed to be at or close to the permanent wilting point for these soils. It has been shown by Veihmeyer, *et al.* (9, 11) that the moisture equivalent of the soils of the Yolo series at Davis is a fair measure of the field capacity of these soils. Thus, after the last considerable rain in the spring, April 16, 1935, the soil in these experiments was assumed to be at its field capacity. Table 2 gives the percentages of relative wetness for each foot in depth in each of the plats studied.

TABLE 2.—*Percentage of relative wetness of soil by foot depths under Atlas barley which gave widely varying yields* *

Plat No.	14S6	13N7	13N6	13S6	13S7	13S4	13S15	13S17
Total barley yield, lbs. per acre	8,221	7,131	4,682	4,426	2,812	2,518	908	Fallow
Relative wetness:								
First foot	31.4	33.0	34.8	30.7	33.8	38.2	41.9	60.8
Second foot	46.4	49.4	54.6	50.4	57.1	59.6	69.6	83.0
Third foot	56.4	54.0	73.5	60.6	68.2	72.3	81.3	87.4
Fourth foot	52.7	56.2	78.4	67.4	77.8	77.2	86.8	87.2
Fifth foot	54.0	64.4	79.0	72.4	79.7	82.3	91.2	96.0
Sixth foot	73.0	82.8	88.4	80.1	89.5	92.1	96.8	102.3
Seventh foot	91.5	93.9	100.0	93.8	94.3	97.2	108.0	106.0
Eighth foot†	97.9	103.8	101.6	94.6	95.8	97.0	106.7	109.2

*Relative wetness equals moisture percentage times 100 divided by moisture equivalent.
†From 7.0 to 7.5 feet

The moisture conditions expressed as relative wetness percentages are shown graphically in Fig. 1.

It will be observed from Fig. 1 and Table 2 that the two highest yielding plats, 14-S-6 and 13-N-7, have pretty well exhausted the available moisture down to the fifth foot, while there is a suggestion of some use of moisture into the seventh foot. Plat 13-S-15, which is the lowest yielding one, has a considerable amount of available moisture in each foot depth below the first. As compared with the adjoining fallow there is a suggestion (though not conclusive evidence) of the use of moisture down to the sixth foot. The other plats lie in between. For some reason not disclosed by the evidence secured in this study, the relative wetness of the soil in plat 13-N-6 is greater than its yield would lead one to expect on the basis of the yields of the other plats.

To change percentages of moisture to actual amounts of water the volume weight of the soil is necessary. No volume weight determinations were made in this study. However, Edlefsen and Bodman (5) have made 154 separate volume weight determinations in several locations and at several depths on Yolo soils near Davis. An average

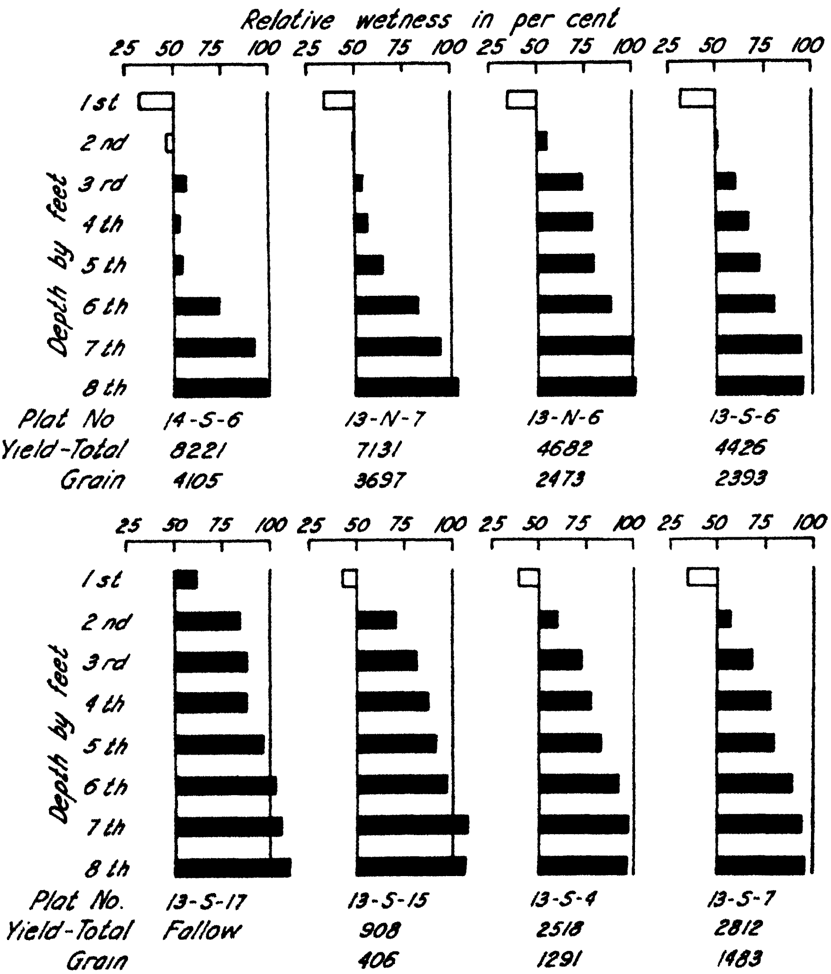

FIG. 1.—Relation between yield of barley in pounds per acre and residual soil moisture expressed as relative wetness. Approximate lower limit of plant absorption is 50%; approximate field capacity is 100%.

of their determinations was computed by the writer and this value (1.2442) is assumed to be the best one obtainable without actual determination for the volume weight of the soil at all depths in these studies, or a weight of 3,375,900 pounds per acre foot of soil. These values are used in all subsequent computations.

DISCUSSION

High transpiration losses from the crop, and in turn from the soil, are inevitable consequences of high yields. This necessarily follows from the very ideas expressed by "transpiration coefficient," "transpiration ratio," and "the water requirement of plants." True, the efficiency in the use of water is enhanced somewhat where the soil is more fertile, but subject to this qualification, and other conditions being equal, the water used in producing a large crop would be greater than that used for a smaller one. The greater the crop then, the greater the amount of water transpired.

Provided that at the start of any considerable period of growth the soil is wet to its field capacity and that during that same period no water be added to the soil, then the larger the crop (a) the more thoroughly must the plants utilize the moisture in the layers of soil permeated by the roots or (b) the greater the depths in the soil from which the larger crop must secure its requisite moisture. But the amount of water available to plants in each acre-foot is largely fixed (1). Therefore, if (without the resupplying of soil moisture) the growth period in question be long, the larger the crop, the greater the soil depths from which the plants must obtain the necessary moisture and the more deeply will the soil be dried out by the crop. From soil moisture principles currently taught it could be predicted by means of *a priori* reasoning that under conditions of deficient moisture supply, the higher the yields of a crop the more deeply in the soil must it secure its necessary moisture supply. The experimental data secured in this instance is consistent with such a theory.

In general, in these studies and similar ones where nitrogen is applied to small grains following sorghums, high yields are associated with an earlier maturity of the crop while delayed maturity was observed on plats yielding the lowest. In fact, it was necessary to allow the bundles harvested from the heavy sucrose treatments to dry out for several days before the weighing for dry matter could be made. In these experimental plats the weeds were scrupulously controlled, but in the adjacent areas which also followed sorghums not so carefully. Considerable variation in yield occurred over the area for various reasons. It was noted that where the yield was the poorest a vigorous late spring and summer weed growth came up in the barley after the growth of the latter was well along. It is recognized that a vigorous thick stand of small grain may discourage the weeds growing along with it because of shading. It is believed in this case, however, that the residual moisture in those spots were the growth of barley had been poor was sufficient to allow a vigorous weed growth to develop, while where the grain yield had been heavy the residual moisture was insufficient. The earlier maturity and lack of late weeds are taken as contributory evidence of low amounts of residual soil moisture where barley yields were high, while late drying out of the crop and a vigorous growth of late weeds suggest residual soil moisture available to plants relatively near the surface.

Variations in yield of barley in these studies have been secured by changing the immediate fertility of the soil. There are other factors which are known to cause variation in yields of any one crop such as

barley, namely, variety, injury from insects or fungous diseases, drowning out or stunting of the crop because water from heavy rains has accumulated in minor depressions, etc. If because of one or more of these factors operating, the yield would be either materially increased, or materially decreased, we would expect a material decrease or increase in the residual moisture in the soil after the crop was harvested. Though data are not presented here with regard to wheat and oats, the "water requirements" of each of these and barley is so close to the other two, that equal yields of these three crops would undoubtedly have resulted in but slight variations in residual soil moisture. In crop-sequence and crop-rotation studies, the variations in residual soil moisture resulting from equal or even normal yields of these crops might be expected to be less than variations in the residual soil moisture under different plats of any one of the three crops where variations in the yields of this crop were induced by material changes in optimum growing conditions. Variations in the yield of any one crop, for example barley, may cause greater differences in residual soil moisture than is caused by planting different but somewhat similar crops, for example wheat or oats instead of barley.

From the viewpoint of crop sequence and particularly with reference to the moisture supply for the crop immediately following the barley crop concerned in this study, it is desirable to compute the amount of water necessary to bring the soil up to its field capacity. The following tabulation, with the plats concerned in the same order as in the tables, gives the depth of water either in effective rainfall or irrigation which must be added to the soil to raise each foot-depth of each plat to its moisture equivalent:

Total barley yield, lbs.	8,221	7,131	4,682	4,426	2,812	2,518	908	Fallow
Inches of water	8.29	6.92	5.14	6.61	5.10	4.99	3.84	2.44

Where the moisture percentage of a sample exceeded its moisture equivalent, no consideration was given to the extra moisture in arriving at the figures given above.

The findings of this study have a bearing on the re-supplying of the subsoil moisture deficiency attendant upon the growing of alfalfa as on upland soils in Nebraska (7) and Kansas (4, 6, 8) which have been depleted of most of the available moisture down to 20 feet or more. Fallowing for 2 years has seemed a feasible practice at Manhattan, Kans., though not at Lincoln, Nebr. At the latter location reliance must be placed upon the gradual accumulation of annual moisture surpluses over current crop requirements to be stored in the subsoil for future use of an alfalfa crop. It is quite evident from the findings of this study that the greater the yields of the annual crops, between two alfalfa plantings, other conditions being similar, the more moisture will be transpired and the less the annual surplus will be to contribute to the sub-soil deficiency. Efforts then to increase the yield of annual crops between alfalfa plantings, except of course by irrigation, should be critically examined. In fact, the effect of the alfalfa crop in enhancing yields of subsequent non-

leguminous crops may in itself prolong the period of re-supplying subsoil moisture deficiencies. On the other hand, if other agronomic objectives, such as better quality of the crop or permanent improvement of the soil, as by the adding of the organic matter of cereal straws, etc., could be attained, the desirability of taking a loss from lower yields of current annual crops in order to store up greater annual moisture surpluses for future use could well be seriously considered.

SUMMARY

The term "transpiration ratio" and similar terms signify that the larger the crop, the greater is the amount of water transpired in producing it, though the absolute values of these ratios may change somewhat with varying conditions of growth. With the available moisture largely fixed and under growing conditions where the soil is not resupplied with moisture during a considerable period of growth, the larger the crop per unit area, the more deeply will it dry out the soil. Data are presented in keeping with these deductions showing the differences in residual soil moisture and its vertical distribution found under barley plats which varied in yield from 908 to 8,221 pounds of total crop per acre.

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CHANGES IN BREAKING STRENGTH OF STRAW OF WHEAT VARIETIES FROM HEADING TO MATURITY[1]

A. T. BARTEL[2]

RESISTANCE to lodging merits consideration in any program of improving small grains. Several workers in recent years have studied the relation between resistance to lodging in wheat varieties and the breaking strength of the straw. These measurements were made on plants harvested at or near maturity without determining whether the comparative breaking strength was the same as at earlier stages when lodging usually occurs. The present investigations of the breaking strength of straw at intervals from preheading to maturity were undertaken in an attempt to answer this question, and to ascertain the strength of straw in wheat plants harvested or dried prematurely as under drouth conditions.

Salmon (4)[3] has described an apparatus for determining the breaking strength of straw. He found a relationship between lodging and breaking strength in winter wheat varieties. A similar relationship was reported by Salmon and Laude (5). Davis and Stanton (2), using the same type of apparatus, made determinations on a large number of oat varieties at Aberdeen, Idaho. In general, the stiffer-strawed varieties, as determined by field observations, showed the highest resistance to breaking. Clark and Wilson (1) described a straw-breaking machine and tested numerous varieties of wheat and barley. They found no significant correlation between breaking strength of straw and lodging Helmick (3) obtained differences in straw strength between two varieties of winter wheat by using an apparatus he devised.

METHODS

Determinations on the breaking strength of straw were made during the years 1932 to 1935 on the Sonora, Baart, and Marquis varieties of wheat grown with normal irrigation at the University Farm, Tucson, Ariz. The mild winters allow spring wheat varieties to be sown in the late fall or winter months without serious frost injury. The average date of seeding for the three varieties was November 1. Baart was also sown early in the spring, the average date being February 21. The varieties were grown in rows 8 feet long and 1 foot apart. A row of each variety was cut as close to the ground as possible on alternate days from 6 days before one-tenth of the heads were emerged from the boot until maturity. The bundles were wrapped with paper, dried in the field, and kept under uniform conditions at least 3 weeks before any determinations were made. The straws in each bundle were thoroughly mixed before making any determinations. The apparatus and method as outlined by Salmon (4) were used.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Arizona Agricultural Experiment Station, Tucson, Ariz. Received for publication November 4, 1936.

[2]Assistant Agronomist, Division of Cereal Crops and Diseases. The author is indebted to C. G. Colcord, scientific aid, for fitting the curves.

[3]Figures in parenthesis refer to "Literature Cited", p. 155.

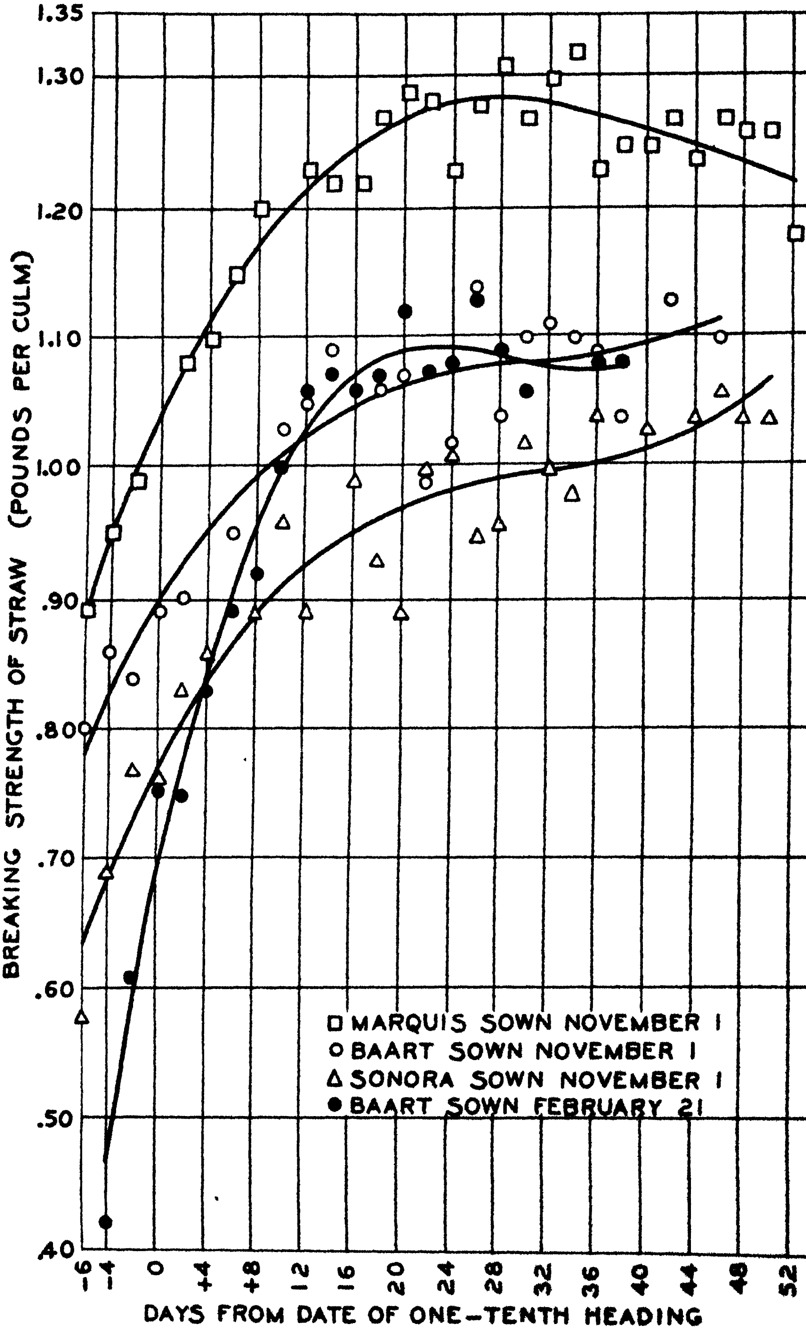

FIG. 1.—Breaking strength of straw of different varieties of wheat.

RESULTS

The breaking strength of straw of the three varieties of wheat when seeded on November 1 and for Baart seeded February 21 is shown in Fig. 1. The data are based on averages of 4 years. The last determination shown for each variety in Fig. 1 was taken at maturity. The average date of one-tenth heading for the fall seeding was March 24 for Baart, March 29 for Sonora, and April 7 for Marquis. The average date for Baart seeded February 21 was May 9. The breaking strength of straw of each variety increased rapidly following one-tenth heading. This rapid increase may be due in part to the increase in breaking strength of the culms that had not headed previously rather than to a continued rapid increase in strength after heading.

Under field conditions at Tucson, Ariz., 6 to 10 days usually elapse between one-tenth heading and full heading in wheat. The maximum breaking strength was not reached until maturity in Sonora and Baart sown November 1. In Marquis it was reached 28 days after one-tenth of the heads were emerged from the boot and then decreased until maturity. The Marquis variety differed from the other two varieties sown November 1 in that it reached the maximum earlier and showed a decrease in breaking strength toward maturity. This was also the case with Baart sown February 21 which reached a maximum 22 days after one-tenth heading, then decreased until maturity. The decrease toward maturity may be due to the fact that the culms on which these two curves are based made their growth under high temperatures. In Marquis this was true because it is a later variety and in Baart because it was sown late.

Lodging notes in the nursery sown on November 1 at Tucson during the same years that the breaking strength of straw determinations were made were as follows: Sonora, 40%; Baart, 22%; and Marquis, 10%. The lodging in these varieties is in inverse proportion to their breaking strength.

CONCLUSIONS

The data indicate that major differences in breaking strength may be determined on samples of straw harvested at any comparable stage from full heading to maturity when the varieties head on about the same date. However, breaking strength of plants may be affected by the environmental conditions under which they make their growth. Thus, the breaking strength of a late variety grown under adverse conditions might be lower in comparison to other varieties than if all varieties had completed their growth under uniform environmental conditions.

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A GREENHOUSE STUDY OF THE EFFECTS OF FINE LIMESTONE APPLIED IN THE ROW WITH LEGUME SEED ON ACID SOILS[1]

LOREN M. GREINER, R. H. WALKER, AND P. E. BROWN[2]

THE application of limestone usually recommended for acid soils is that amount which, applied broadcast, will supply sufficient calcium carbonate to neutralize the acidity of the soil to a depth of about 7 inches. Recently it has been suggested that small amounts of lime applied in the row might give just as satisfactory results.

This row method for the application of small amounts of limestone gained attention when McCool (7)[3], in 1927, reported the results of a series of field trials at the Michigan Agricultural Experiment Station. From his results on Fox sandy loam he concluded that 750 pounds of finely ground limestone added in the row were as effective as much larger amounts applied broadcast. In a more complete report of his findings in 1930, McCool (8) concluded that the practice of using small amounts of lime in the row with certain legumes on some soil types made conditions more favorable for growth while on other types the method did not prove effective.

As a result of a series of experiments begun in 1927 and covering a period of 3 years, Albrecht and Poirot (2) in Missouri concluded that small amounts of 30-mesh limestone drilled with inoculated seed on a sour soil known as Gerald silt loam were as effective as much larger amounts of limestone applied broadcast. At the Kansas station (5) applications of lime drilled in the row with sweet clover seed were found to be successful.

The purpose of the work reported here was to study the effects of applications of small amounts of fine limestone applied in the row with legume seed on crop growth and on the reaction and numbers of micro-organisms in certain Iowa soils under greenhouse conditions.

EXPERIMENTAL

Two acid loessial Iowa soils, a Marshall silt loam surface soil and subsoil and a Grundy silt loam surface soil, were selected for these experiments. The lime requirement of the Marshall silt loam, as determined by the Hardy-Lewis method, was 1.87 tons per acre for both the surface soil and the subsoil, and for the Grundy silt loam surface soil the lime requirement was 3.10 tons per acre. The purity of the fine limestone employed, in terms of $CaCO_3$, was 95.5%. In the screen test of the limestone 98.4% passed through a 100-mesh screen. During the winter months while the experiment was under way artificial light was supplied to the plants.

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[3]Figures in parenthesis refer to "Literature Cited", p. 164.

SERIES I

In order to compare the effects of the row method of application of limestone on Marshall silt loam with limestone mixed throughout the surface soil, subsoil, or both, the following experiment was carried out, using deep pots in duplicate for each treatment:

1. No treatment.
2. Fine limestone applied at the rate of 500 pounds per surface acre in each of five 1-inch rows, one in the center of the 6-inch square surface area and one in each corner, 1 inch from the side of the pot.
3. Fine limestone applied in the surface soil at the rate of 2 tons per 2 million pounds of soil.
4. Fine limestone applied in the subsoil at the rate of 2 tons per 2 million pounds of soil.
5. Fine limestone applied to the entire amount of soil at the rate of 2 tons per 2 million pounds of soil.

For the experiments with the Marshall silt loam, surface soil was placed in the upper half of the pots and subsoil in the lower half. In the Grundy silt loam experiment, surface soil only was used in the pots. Sweet clover and alfalfa were grown on the Marshall silt loam and sweet clover on the Grundy silt loam. At the time of planting, samples of surface soil were taken for the determination of pH. A determination of the plant height for each plant was made 65 days after planting and again 21 days later. After 90 days of growth the crops were harvested, samples of the soil were taken for pH determinations, and the root systems were examined.

Crop growth.—The mean height in inches of the plants in each soil, as determined for the 65-day growth period and again for the 86-day growth period, is recorded in Table 1. In order to determine the significance of the effects of treatments upon plant height, using the 65-day mean in combination with the 86-day mean, an analysis of variance of the data for each of the three crops grown was calculated. The results are recorded in Table 2.

With the sweet clover grown on Marshall silt loam significant differences were found between the means of treatments. These differences indicate that fine limestone in the row depressed the rate of growth of the plants significantly. Some depressive effect, although not so great, was noted also upon the growth of the sweet clover plants by the application of fine limestone sufficient to meet the lime requirement of the soil when mixed both with the surface soil and the subsoil.

No significant difference is indicated by the analysis of variance between the mean height of the alfalfa grown on the untreated Marshall silt loam and on that to which lime had been applied in the row. It appears, however, that lime applied in the surface or the subsoil increased the growth of the alfalfa plants significantly, whereas, there was some depressive effect when it was applied to the entire amount of soil. In the case of the sweet clover plants grown on Grundy silt loam, there was a significant difference only between the height

TABLE 1.—*Mean height of alfalfa and sweet clover plants grown on Marshall and Grundy silt loams variously limed.*

Treatment	Pot No.	65 days after planting			86 days after planting		
		Marshall silt loam		Grundy silt loam	Marshall silt loam		Grundy silt loam
		Sweet clover, inches	Alfalfa, inches	Sweet clover, inches	Sweet clover, inches	Alfalfa, inches	Sweet clover, inches
Check	A	7.40	2.94	3.28	19 09	7.57	9.65
	B	7 45	2.65	2.75	19.00	3.80	10.60
	Mean	7.42	2.79	3.01	19.04	5.68	10.12
Fine limestone applied in the row	A	5.88	2.04	3.24	9.50	5.92	9.78
	B	5.18	2.38	3.21	15.25	5.44	10.72
	Mean	5.53	2.21	3.22	12.38	5.68	10.25
Fine limestone applied to surface soil	A	5.68	3.39	1.54	15.14	9.06	6.25
	B	6.45	2.82	2.21	18.80	7.63	8.88
	Mean	6.06	3.10	1.87	16.97	8.34	7.56
Fine limestone applied to subsoil	A	4.73	2.90	2.89	14.31	7.75	13.25
	B	5.60	3.46	2.75	13.90	9.00	11.65
	Mean	5.16	3.18	2.82	14.10	8.37	12.45
Fine limestone applied to the entire amount of soil	A	6.36	1.63	2.23	17.00	4.48	8.79
	B	7.06	1.87	3.40	19.00	4.95	12.64
	Mean	6.71	1.75	2.81	18.00	4.71	10.71

TABLE 2.—*Analysis of variance of the mean height of alfalfa and sweet clover plants grown on Marshall and Grundy silt loams variously limed.*

Source of variation	Degrees of freedom	Mean square		
		Marshall silt loam		Grundy silt loam
		Sweet clover	Alfalfa	Sweet clover
Total	19	30.9	6.0	16.8
Within classes	9	2.9	1.1	1.6
Between date means	1	492.0†	78.1†	279.1†
Between means of treatment	4	13.1*	5.1*	4.6*
Interaction	5	3.2	1.1	1.7

*Significant.
†Highly significant.

of the plants grown in the soil receiving lime in the upper half of the pot and those grown in the soil receiving lime in the lower half. The latter were significantly higher than the former.

Soil reaction.—As determined by pH at the close of the experiment a slight lowering of the acidity in the soil below the rows indicated that the fine limestone did not remain entirely at the point of application. As compared to the unlimed surface soil, a difference of 0.4 pH occurred in the Grundy silt loam at a depth of 4 cm.

Nodules.—Limestone, when applied in the row, appeared to cause a concentration of nodules on the tap roots and the small branch roots of the plants, extending from the point of application in the row to 4 to 6 cm below that point.

Damping-off.—Buchholtz (3) examined the seedlings of the plants in this series soon after emergence and found that some of the plants were infected by a pythium species. The symptom noticed was a collapse of the primary root and the lower portion of the hypocotyl.

SERIES II

The experiments in Series II were planned to determine the effects of applications of fine limestone applied in the row upon the emergence of alfalfa, sweet clover, and red clover seedlings in Marshall and Grundy silt loams. The numbers of micro-organisms and the changes in reaction in the Marshall silt loam were also studied.

The treatments for these experiments were as follows:

1. Surface soil sterilized for 1 hour in an autoclave at 15 pounds pressure.
2. Surface soil treated with fine limestone applied in small amounts in the row at the time of seeding.
3. Untreated surface soil.

About 25 pounds of the soil selected for each treatment were placed in each of duplicate 15 x 20 inch shallow flats. Inoculated seeds of each of the three crops, alfalfa, sweet clover, and red clover, were planted in randomized rows in each of the flats.

Damping-off.—Counts of the emerged plants in two experiments on Marshall silt loam, representing 840 seeds planted for each of the three crops, were made soon after emergence. The results are recorded in Table 3. The results of the counts made for the Grundy silt loam, also recorded in Table 3, represent a total of 240 seeds for each of the crops.

An average of 3.4% more alfalfa seedlings, 3.7% more sweet clover seedlings, and 8.2% more red clover seedlings emerged in the soils treated with fine limestone applied with the seed than in the untreated soils. For the alfalfa, the number which emerged on the soils treated with fine limestone was still 14.9% less than emerged when sterilized seeds were planted on sterilized soil. The difference for sweet clover was even greater, 15.2%, and for red clover still greater with 22.1%.

From a comparison of the number of diseased seedlings emerged for each crop, which indicated consistently greater numbers for those seedlings emerged in the limestone-treated soil, it appears that the limestone was effective in reducing the infection produced by the parasitic organisms.

Number of micro-organisms.—A study of the effects on numbers of micro-organisms of fine limestone applied in the row with the seeds was made in the experiment on Marshall silt loam indicated as No. 1 in Table 3. The technic for the counting of micro-organisms by the direct microscopic ratio method described by Thornton and Gray (11) was followed

Eighteen days after the crops of alfalfa, sweet clover, and red clover were seeded, samples were collected by means of sterile test tubes from each of the flats in the experiment. Four drops of the mixed soil and indigo suspension from each sample were placed on each of four slides, fixed by drying in the air, and stained with erythrosine. Using an oil immersion lens, counts of the number of indigo particles and stained micro-organisms observed on each of four fields in each drop were made.

An analysis of variance of the data indicated no significant differences between the numbers of stained micro-organisms in the check soil and the sterilized soil, but the differences between the numbers in the check soil and the soil to which fine limestone had been applied in the row were highly significant. The mean number of micro-organisms, as determined for the check soil, was 46.9 million per gram of soil. This was 46.8 million less than the average of the samples taken at the 0 to 2 and the 2 to 4 cm depths in the soil receiving fine limestone in the row.

SERIES III

Moisture as a factor in fine limestone penetration.—In this series it was desired to determine the penetration of fine limestone as indicated by pH changes after application in the row in soils of high and low moisture content.

In order to determine the rate of penetration under high moisture conditions, duplicate 11 x 41 x 48 cm greenhouse boxes of each of the two soils, Grundy and Marshall silt loam surface soils, were placed in shallow tins filled with distilled water. During the course of the

TABLE 3.—*Emergence of healthy and diseased seedlings on treated and untreated Marshall and Grundy silt loam.*

Crop	Marshall silt loam				Grundy silt loam		Mean	
	No. 1		No. 2					
	Plants emerged*	Diseased*	Plants emerged	Diseased	Plants emerged	Diseased	Plants emerged	Diseased
	Sterilized Surface Soil							
Alfalfa	57.5	0.0	66.9	0.2	79 4	0.4	67.8	0.2
Sweet clover	56.7	0.0	50.6	0.2	64.0	0.4	57.1	0.2
Red clover	70.3	0.8	39.0	0.8	56.7	0.4	55.3	0.7
	Fine Limestone Applied in the Row							
Alfalfa	56.6	11.4	53.9	17.9	47.3	26.2	52.9	18.5
Sweet clover	35.3	6.6	42.7	12.7	47.7	30.3	41.9	16.5
Red clover	33.9	6.9	29.2	7.5	36.6	18.8	33.2	11.1
	Unlimed Surface Soil							
Alfalfa	50.8	7.4	40.6	5.9	57.0	23.5	49.5	12.3
Sweet clover	44.8	3.3	36.0	7.4	33.9	18.4	38.2	9.7
Red clover	27.2	4.1	16.3	2.5	31.6	14.2	25.0	6.9

*Mean calculated on the basis of 100 seeds planted.

experiment no moisture was added to the surface of the soil. Four weeks after the experiment was started fine limestone was applied ½ inch below the surface of the soil in a row 48 cm in length at the rate of 500 pounds per surface acre. Thirty-three days after the limestone was applied in the row samples were taken at 0 to 2, 2 to 4, and 4 to 6 cm below the surface in the row and at 1½ and 3 cm to the side of the row by means of a graduated cork borer.

The moisture content of the soils at the surface remained, throughout the experiment, at about 28% for the Marshall and about 41% for the Grundy. For the Marshall, the pH of the samples taken varied from 6.77 in the row to 5.70 for those taken 6 to 10 cm below the row. Near the surface, at 1½ and 3 cm to the side of the row, the pH was 5.50. In the Grundy silt loam the pH change was found to coincide very closely with that of the Marshall. In the row the pH was 6.54. At 6 to 10 cm below the row it was 5.36 and at 1½ cm and 3 cm to the side of the row it was 5.23.

In order to determine whether or not the percentage of moisture in the soil surrounding the limestone was a factor in the rate of penetration, a second experiment was planned in which three 6 x 6 x 16 inch wooden pots with removable sides were filled with Marshall surface soil and placed in a shallow tin filled with distilled water. Thirty days after the experiment was started fine limestone at the rate of 500 pounds per surface acre was placed in a 6-inch row, ½ inch below the surface of the soil in each of three pots. Fifty-eight days later a side was removed from each of the pots and samples were taken parallel with the row by inserting a 1½ cm cork borer into the column of soil from the exposed side. At the surface of the soil in the row the average moisture content of the samples taken was 20.6%. The mean pH, as determined for these samples, was 6.54. At 2 to 4 cm below the surface of the row the pH changed to 6.12. This was only 0.02 pH above the minimum of 6.10 at 4 to 6 cm below the surface of the row.

By reducing the moisture content of the Marshall silt loam in the row from 28% to 20.6%, the depth to which the limestone penetrated, as determined by pH, was decreased.

It would appear from these experiments that the downward movement of fine limestone, as determined by pH changes, is directly a function of the moisture content of the soil.

DISCUSSION

The results of this investigation lead to the belief that small amounts of fine limestone when applied in the row with certain legume seed may cause a depression in the early growth of the plants on certain soil types. Midgley (6) found that crop growth was often injured when fine high-calcic limestone was applied to very acid soils in excess of their lime requirement. He observed no injury when calcium carbonate was replaced by calcium silicate. Leaching was found to remove the injurious material and the unfavorable effects were overcome with time. High pH values due to excessive lime additions did not seem to be the major cause of the trouble. Pierre and Browning (9) suggest that temporary injurious effects of overliming in experi-

ments conducted by them were associated with a disturbed phosphate nutrition of the plants. Scarseth (10) has suggested that the depressed effect which frequently results from light applications of lime to acid soils is due to a high silica-sesquioxide ratio which lowers the solubility of the phosphorus in the soil. He believes that if the soluble phosphate is maintained at a high level the depressing effect should not occur. It may be desirable, therefore, to recommend an application of phosphate fertilizer with fine limestone when applied in the row.

Albrecht and Jenny (1) report that high calcium concentrations were found to prevent a damping-off disease and that certain legumes may grow in an acid soil if soluble calcium is available. Buchholtz (3) found that a steamed acid soil of northern Iowa would grow a higher percentage of alfalfa plants than a neutral soil not steamed. The same effect, to a limited degree, was brought about in an alfalfa planting by applying limestone to the soil. Fine limestone when applied in the row may be of value and have its place as a method of increasing the supply of available calcium to the seedlings and in decreasing damping-off infection when applied with certain legume seed on acid soils.

SUMMARY AND CONCLUSIONS

Greenhouse experiments were carried out on two acid Iowa soils, Marshall and Grundy silt loams, to determine the value of fine limestone applied in the row with certain legume seed.

Small amounts of fine limestone applied in the row with sweet clover seed on Marshall silt loam caused a depression in the early growth of the plants when grown in deep greenhouse pots. There was no depression in the case of alfalfa nor with sweet clover on Grundy silt loam.

Limestone applied in the row appeared not to be depressive to the formation of nodules.

The death rate of seedlings caused by pythiaceous fungi was decreased 3.4% for the alfalfa, 3.7% for the sweet clover, and 8.2% for the red clover by applying fine limestone with the seed at the time of planting.

As determined by the direct microscopic ratio method fine limestone, when applied in the row with legume seed on Marshall silt loam, stimulated the growth of micro-organisms. The average number of micro-organisms counted for samples taken 0 to 4 cm deep in the row was 93.7 million per gram of soil. This was 46.8 million more than was found in the check soils.

As indicated by pH determinations, penetration of limestone when applied in the row was evident in soils receiving water from below only.

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BOOK REVIEW

FIFTY YEARS OF FIELD EXPERIMENTS AT THE WOBURN EXPERIMENTAL STATION

By Sir E. John Russell and Dr. J. A. Voelcker, with a statistical report by W. G. Cochran. New York: Longmans, Green and Co. XVII+392 pages, illus. 1936. $7.50.

THE work of the Woburn Experimental Station founded in 1876 is almost as familiar to workers in agricultural science as that of the older Rothamsted Station of which it is now a part. This volume, which is one of the Rothamsted Monographs on Agricultural Science, brings together and evaluates the now classic experiments dealing with soil productiveness as influenced by animal feeding with concentrated foods, the continuous growing of cereals, green manuring practices, the handling of grass lands, and sheep and cattle feeding experiments.

In Part I, Dr. Voelcker describes the experiments and tabulates the results. Part II consists of a statistical examination of the results and their correlation with weather conditions. The fact that the experiments were laid out by the old method of systematically arranged single plats without reference to soil variation has made it impossible fully to evaluate the results with certainty. This matter is gone into at some length in the introduction and again in Part II. It furnishes much food for thought and can be very profitably studied by every American worker in the same fields.

In Part III, Sir John Russell discusses the results at length and their bearing on agricultural science and practice, while Part IV fully describes the soils of the experimental plats. The remainder of the book consists of an appendix of primary data and the index.

The value of the book lies in the light which these long-time experiments throw on such fundamentals as the use of natural and artificial manures, crop rotation, and soil deterioration and its causes. The volume constitutes a worthy addition to the Rothamsted monographs. (R. C. C.)

AGRONOMIC AFFAIRS

FOURTH INTERNATIONAL GRASSLAND CONGRESS

A PRELIMINARY program and the application forms for membership in the Fourth International Grassland Congress to be held in England in July of this year are now available. Prof. R. G. Stapledon, Director of the Welsh Plant Breeding Station and of the Imperial Bureau for Herbage Plants at Aberystwyth, Wales, is President of the Congress.

The paper reading sessions of the Congress will be held at Aberystwyth from July 13 to 19 and will be preceded and followed by tours of grassland centers and selected farms. The Congress fee will be 2 pounds sterling and will entitle one to attend all sessions and to receive the printed transactions, including all abstracts in advance of the Congress, as well as other incidental matter pertaining to the Congress. A fee of 1 pound sterling will entitle wives accompanying members to all the privileges of membership except the transactions. Estimated costs of the tours may be obtained upon request.

All particulars regarding acceptance of papers and dates for receipt of abstracts and manuscripts may be had from the Joint Secretaries, Agricultural Buildings, Aberystwyth, Great Britain. The preliminary program, membership forms, and general information regarding the Congress may also be obtained from this address.

NEWS ITEMS

President Richey has named Professor R. D. Lewis of Ohio State University and O. S. Fisher of the U. S. Dept. of Agriculture to represent the Society on the Seed Council of North America.

Dr. E. R. Collins of the North Carolina Experiment Station has been named by President Richey to serve on the Sub-committee on Fertilizer Application.

Dr. Carroll P. Wilsie has been appointed Research Associate Professor of Farm Crops at the Iowa State College to fill the vacancy occasioned by the death of Professor F. S. Wilkins. Dr. Wilsie received his B.S. degree from the University of Wisconsin, did graduate work at the University of Illinois and received his Ph.D. degree from Michigan State College in 1931. During the past five years he has been Agronomist and Assistant Professor in the University of Hawaii. At the Iowa State College, Dr. Wilsie will be in charge of forage crop investigations.

ERRATUM

IN the title to the Note by Mr. F. A. Coffman appearing on page 79 of the January number of the Journal, the word "Specific" was inadvertently substituted for the word "Species" in the author's manuscript. The correct title should read "Species Hybridization, A Probable Method for Producing Hardier Winter Oats."

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STUDIES IN YIELD COMPARISONS OF RICE[1]

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RICE is one of the most important crops in China, as it is the staple food of almost half of the population. Thus, for the national welfare, it is imperative that the study of problems on any phase of rice improvement needs the highest scientific effort and technic. Since 1928 the author has been engaged in such studies and has conducted a series of experiments on rice at the University farm of the College of Agriculture, Lingnan University, Canton, China. The climatic conditions there are especially suitable for growing rice The annual rainfall varies from 60 to 80 inches, and there are no spells of cold that are injurious to the crop. Thus it is possible to grow two crops of rice on the same field during one year

The experimental designs used are those that have been advocated by Fisher and Wishart (2)[3] at the Rothamsted Experiment Station, and the data have been analyzed by the methods published by Fisher (1) Part of the results were published in Chinese (4), while other parts are in the course of preparation The present paper gives a brief summary of these results, but deals with only three groups of the experiments The remainder will be published later. The three points considered here are (a) the effect of varying the amount of seed per row, (b) the effect of varying the number of seedlings per hill, and (c) a combined study of the number of plants per hill and distance between hills.

EFFECT OF VARYING AMOUNT OF SEED PER ROW

The object of this experiment was to find out what effect varying quantities of seed used in the rows had on yield and at the same time to determine the quantity of seed that would produce the highest yield.

[1]Contribution from the Agricultural Department, Lingnan University, Canton, China. Received for publication November 13, 1936.

[2]Assistant Professor of Plant Breeding. The author wishes to express his gratitude to Professor H. H. Love of Cornell University for his suggestions in the preparation of this paper and to Dr. J. Wishart of Cambridge, England, for his advice in the methods of calculation and interpretation of the data. The author, however, assumes responsibility for all calculations and interpretations of results.

[3]Figures in parenthesis refer to "Literature Cited", p. 185.

RESULTS OF 1932 CROP

As stated above, two crops of rice can be grown on the same field in the same year. In general practice the first crop is usually planted in the seedbed in March or April and transplanted to the field about one month later, but for our purposes seed was usually sown directly in the field without transplanting. The first crop matures about the last of July. The seed of the second crop is planted in the bed about one month before the first crop is mature and transplanted after the first crop is harvested. The harvesting season for the second crop varies from the end of October to the first of December

The design of the 1932 experiment is shown in Diagram I, where one variety (Tung-wan-beh) with six treatments, *viz.*, 3, 6, 9, 12, 15, and 18 grams of seed per row, respectively, was randomized in each block and replicated six times.

I			II			III			IV			V			VI		
18	3	12	15	9	6	12	6	18	9	15	3	12	18	9	6	3	15
9	15	6	3	18	12	15	3	9	6	12	18	15	3	6	18	9	12

DIAGRAM 1.—Plan of 1932 planting Roman numerals represent blocks; Arabic numerals grams of seed per row.

Each plat had five rows, each row being 14 feet long with $1\frac{1}{2}$ feet between rows. The yields are given in Table 1.

TABLE 1.—*Yields in grams for different rates of seeding in 1932.*

Block No.	Treatment in grams of seed per row						
	3	6	9	12	15	18	Total
I	28.1	29.4	25.4	38.5	33.6	37.4	192.4
II . . .	29.5	35.5	26.6	30.6	36.1	30.4	188.7
III . . .	35.4	38.3	31.6	38.0	27.7	38.3	209.3
IV. . . .	30.6	36.7	27.9	34.1	35.6	36.8	201.7
V. . . .	31.5	35.4	43.0	33.1	38.6	40.0	221.6
VI . .	42.3	41.0	33.8	41.0	41.7	36.3	236.1
Total. . .	197.4	216.3	188.3	215.3	213.3	219.2	1,249.8
Average.	32.9	36.0	31.4	35.9	35.5	36.5	34.7

The standard error $= \sqrt{\frac{15.76}{6}} = 1.62.$

The data in Table 1 give a standard error equal to 1.62 and the calculated z value from Fisher (1) shows that the variance due to different treatments is not significantly greater than would have been due to random error. Although apparently there is a little difference between the mean yields (ranging from 32.9 for 3 grams to 36.5 for 18 grams) due to treatments, there is no significant difference.

TABLE 2.—*Yields of grain in grams, average of 5-row plats, first crop, 1933.*

Variety	Grams of seed per row	Block No. I	II	III	IV	V	VI	Treatment total	Variety total
					Section A				
	3	553	453	470	435	451	475	2,837	
	6	539	460	581	499	492	478	3,049	
	9	542	487	533	501	546	492	3,101	
A	12	494	445	574	567	489	522	3,091	21,341
	15	497	527	509	466	592	561	3,152	
	18	525	463	531	522	531	472	3,044	
	24	477	496	551	515	502	526	3,067	
	3	497	434	435	365	506	478	2,715	
	6	422	391	548	452	487	423	2,723	
	9	466	438	488	439	475	532	2,838	
B	12	443	410	576	439	510	432	2,810	19,429
	15	420	474	472	429	470	421	2,686	
	18	516	409	491	468	526	461	2,871	
	24	471	443	528	447	457	440	2,786	
	3	360	379	442	366	467	441	2,455	
	6	419	407	500	485	469	424	2,764	
	9	542	461	454	412	487	485	2,841	
C	12	460	380	445	445	514	496	2,740	19,318
	15	496	466	522	490	494	456	2,924	
	18	447	432	519	431	466	494	2,789	
	24	473	407	520	457	498	450	2,805	
Totals		10,059	9,322	10,689	9,630	10,429	9,959	60,088	
					Section B				
	3	412	449	385	346	388	363	2,343	
	6	486	460	413	389	380	468	2,596	
	9	542	548	466	441	479	434	2,910	
A	12	522	521	440	467	522	443	2,915	19,661
	15	457	558	495	432	490	447	2,879	
	18	567	506	562	440	494	528	3,097	
	24	473	504	493	469	495	487	2,921	
	3	459	430	400	429	411	310	2,439	
	6	438	390	388	454	421	436	2,527	
	9	480	427	411	405	454	448	2,625	
B	12	465	436	405	378	400	416	2,500	17,972
	15	443	495	379	465	404	438	2,624	
	18	416	493	422	418	379	436	2,564	
	24	482	463	420	453	431	444	2,693	
	3	360	409	420	395	384	413	2,381	
	6	444	456	419	398	401	391	2,509	
	9	470	433	403	453	420	509	2,688	
C	12	467	543	439	413	388	414	2,664	18,108
	15	520	390	459	443	430	410	2,652	
	18	467	423	377	459	420	391	2,537	
	24	448	446	421	429	418	515	2,677	
Totals		9,818	9,780	9,017	8,976	9,009	9,141	55,741	

RESULTS OF FIRST CROP, 1933

The methods used were the same as in the previous year, but three varieties were studied instead of one. Each of these three varieties was subjected to the same seven treatments, *viz.*, 3, 6, 9, 12, 15, 18, and 24 grams of seed per row, respectively, giving 21 different plats for one block. In arranging the plats the experiment was divided into two

TABLE 3.—*Total yields (in grams) of varieties and treatments for first crop, 1933.*

Variety	Grams of seed per row							Totals	Average
	3	6	9	12	15	18	24		
				Section A					
A	2,837	3,049	3,101	3,091	3,152	3,044	3,067	21,341	508.12
B	2,715	2,723	2,838	2,810	2,686	2,871	2,786	19,429	462.59
C	2,455	2,764	2,841	2,740	2,924	2,789	2,805	19,318	459.95
Totals	8,007	8,536	8,780	8,641	8,762	8,704	8,658	60,088	—
Average	445	474	488	480	487	483	481	—	476.88
				Section B					
A	2,343	2,596	2,910	2,915	2,879	3,097	2,921	19,661	468.12
B	2,439	2,527	2,925	2,500	2,624	2,564	2,693	17,972	427.91
C	2,381	2,509	2,688	2,664	2,652	2,537	2,677	18,108	431.14
Totals	7,163	7,632	8,223	8,079	8,155	8,198	8,291	55,741	—
Average	398	424	457	449	453	455	461	—	442.3

TABLE 4.—*Analysis of variance of data given in Table 3*

Variation due to	D.F.	Sum of squares	Mean squares	½ $\log_e$	z	P
			Section A			
Blocks	5	59962.7307	11992.546	—	—	—
Varieties	2	61592.0164	30796.008	1.71375	1.62450	.01
Treatments	6	23803.2227	3967.203	.68900	.5975	.01
Interaction between varieties and treatments	12	12677.8725	1056.49	.02725	—	—
Error	100	119546.6027	1195.466	.08925	—	—
Total	125	277582.445				
			Section B			
Blocks	5	37770.0397	7554.008	—	—	—
Varieties	2	41928.7778	20964.3889	1.52133	1.44321	.01
Treatments	6	57238.3333	9539.7222	1.12774	1.04962	.01
Interaction between varieties and treatments	12	27560.6667	2296.7222	.41583	.33771	—
Error	100	116880.1270	1168.8013	.07812	—	—
Total	125	281377.9445				

parts, A and B, each with six blocks. For section A, a semi-random arrangement was used, that is, the varieties were arranged in a somewhat systematic way but the treatments were entirely randomized. In section B, however, both varieties and treatments were randomized. The detailed planting plan is shown in Diagram 2 and the yields are given in Table 2.

In order to simplify the calculation of the results, the data have been summarized in Table 3. The analysis of variance is given in Table 4.

The results given in Table 4 show that the differences between varieties and between treatments are significant, while those due to interactions between varieties and treatments are not significant. The results obtained by use of the standard error are given in Tables 5 and 6.

TABLE 5. *Summary of yields for varieties, first crop, 1933*

Yield	Varieties A	B	C	Mean	S.E.
		Section A			
Av. gr.	508	462	460	476.8	5.235
Per cent	106.5	96.9	96.5	100	1.098
		Section B			
Av. gr.	468	428	431	442.39	5.275
Per cent	105.8	96.7	97.4	100	1.192

Variety A is significantly higher in yield than either variety B or C.

TABLE 6. *Summary of yields for treatments, first crop, 1935*

Yield	Grams of seed per row 3	6	9	12	15	18	24	Mean	S.E.
				Section A					
Av. gr.	445	474	488	480	487	483	481	476.8	8.142
Per cent	93.3	99.4	102.3	100.7	102.1	101.3	100.9	100	1.707
				Section B					
Av. gr.	398	424	457	449	453	455	461	442.39	8.058
Per cent	90.0	95.8	103.3	101.5	102.4	102.8	104.2	100	1.821

The data in Table 6, Section A, show that all seeding rates under semisystematic arrangement gave the same results except the rate of 3 grams per row which gave a smaller yield. The data in Table 6, Section B, show that all treatments under complete randomization gave the same yields for different treatments except for the rates of 3 and 6 grams per row, which gave smaller yields.

By combining the data of Sections A and B as one experiment, the results may be summarized for treatments as in Table 7.

Section A

A-3 B-18 C-12	B-24 C-15 A-6	C-18 A-9 B-3	A-12 B-6 C-24	B-9 C-3 A-15	C-6 A-18 B-12	A-24 B-15 C-9	B-18 C-12 A-3	C-15 A-6 B-24	A-9 B-3 C-18	B-6 C-24 A-12	C-3 A-15 B-9	A-18 B-12 C-6	B-15 C-9 A-24
B-24 C-15 A-6	C-18 A-9 B-3	A-12 B-6 C-24	B-9 C-3 A-15	C-6 A-18 B-12	A-24 B-15 C-9	B-18 C-12 A-3	C-15 A-6 B-24	A-9 B-3 C-18	B-6 C-24 A-12	C-3 A-15 B-9	A-18 B-12 C-6	B-15 C-9 A-24	C-12 A-3 B-18
C-9 A-3 B-18	A-6 B-24 C-12	B-3 C-15 A-9	C-18 A-12 B-6	A-15 B-9 C-24	B-12 C-3 A-18	C-6 A-24 B-15	A-3 B-18 C-9	B-24 C-12 A-6	C-15 A-9 B-3	A-12 B-6 C-18	B-9 C-24 A-15	C-3 A-18 B-12	A-24 B-15 C-6

Section B

C-15 B-24 A-12	A-6 B-18 B-12	A-9 A-24 A-18	C-12 B-15 A-15	C-18 B-3 C-24	C-3 C-6 A-3	B-6 C-9 B-9	A-3 A-15 A-6	C-18 B-3 A-12	B-9 B-6 B-18	C-12 B-12 A-9	A-24 A-18 C-6	C-24 B-15 C-15	C-3 B-24 C-9
C-12 A-3 C-6	C-18 C-9 A-15	B-12 B-24 C-15	B-6 B-15 A-9	B-18 A-18 C-3	A-24 A-6 B-9	A-12 C-24 B-3	C-24 A-18 B-12	C-12 C-6 B-18	B-3 C-18 A-9	A-12 A-24 B-9	B-15 B-6 B-24	C-3 A-6 A-3	C-9 A-15 C-15
A-15 B-15 B-18	B-12 C-6 C-12	C-15 B-9 B-24	A-6 A-24 A-3	C-24 B-9 B-3	C-18 C-3 A-18	A-12 A-9 C-9	A-6 C-15 A-12	B-9 B-12 B-18	C-24 A-24 A-15	C-9 C-3 B-24	A-3 B-3 A-9	B-6 A-18 B-15	A-6 C-6 C-12

DIAGRAM 2.—Planting plan for first crop, 1933. Letters indicate varieties and numerals grams of seed per row.

Block IV							Block V							Block VI						
A-24 A-6 B-24 A-18	A-3 A-15 C-18 D-12	C-24 D-6 A-9 C-9	D-9 D-15 C-15 C-6	B-3 D-18 B-9 D-3	B-15 C-12 D-24 A-12	B-18 C-3 B-12 B-6	C-3 C-24 D-18 C-9	B-18 A-12 B-24 C-15	C-6 D-9 A-9 D-6	B-12 C-12 A-3 D-3	A-15 A-24 A-6 D-15	A-18 B-9 B-15 C-18	D-24 D-12 B-3 B-6	A-15 D-12 A-9 B-15	B-9 D-9 D-24 B-3	A-24 A-3 B-18 B-6	C-3 A-6 B-12 D-18	D-6 C-18 C-12 B-24	C-24 A-18 D-3 C-9	D-15 C-6 A-12 C-15
Block I							**Block II**							**Block III**						
B-18 D-15 D-9 A-12	A-9 A-24 C-6 D-24	C-15 D-18 C-12 C-3	A-18 B-3 B-9 D-6	C-24 B-6 A-15 D-3	A-3 A-6 B-24 B-12	C-9 D-12 B-15 A-18	D-6 A-24 D-12 A-18	D-3 D-15 B-9 C-12	A-3 B-24 D-18 A-15	B-15 B-18 A-6 C-24	A-12 D-9 B-3 C-9	C-6 B-6 C-15 B-12	D-24 C-18 A-9 C-3	B-15 A-6 C-24 A-12	D-18 A-15 C-9 C-3	A-18 D-3 B-9 B-6	D-15 D-6 D-12 D-24	A-24 C-12 B-3 A-9	B-24 B-18 B-12 C-15	C-6 A-38 C-18 D-9

DIAGRAM 3.—Planting plan, second crop, 1933. Letters indicate varieties; Roman numerals blocks; and Arabic numerals rates of seeding.

TABLE 7.—*Summary of yields in grams for treatments, first crop, 1933.*

Yield	Grams of seed per row							Mean	S.E.
	3	6	9	12	15	18	24		
Av., gr	421	449	472	464	470	469	471	459.64	5.77
Per cent.	91.6	97.7	102.7	100.9	102 2	102	102.5	100	1.25

The 3-gram rate of seeding still gives the lowest yield, while the 6-gram rate is significantly lower than the yields from 9, 15, 18, and 24 grams per row, but in comparison with the 12-gram rate the difference is not significant

RESULTS OF SECOND CROP, 1933

In this experiment there were four varieties each having seven different treatments. This gave 28 different plats in each block. The planting plan is shown in Diagram 3 and the yields and analysis of variance are given in Tables 8, 9, and 10.

TABLE 8 —*Yields in grams, second crop, 1933.*

Variety	Grams of seed per row	Block No						Treatment total	Variety total
		I	II	III	IV	V	VI		
A	3	297	277	335	247	345	321	1,822	16,749
	6	357	476	328	433	266	379	2,239	
	9	422	494	342	426	376	387	2,447	
	12	556	374	518	317	406	403	2.574	
	15	456	551	347	420	521	414	2,709	
	18	375	477	343	393	492	441	2,521	
	24	365	274	353	505	422	518	2,437	
B	3	270	216	262	198	225	177	1,348	14,262
	6	293	321	358	247	196	316	1,731	
	9	534	452	353	277	307	348	2,271	
	12	469	400	415	320	344	298	2,246	
	15	473	354	304	384	364	301	2,180	
	18	496	376	399	349	404	285	2.309	
	24	476	352	329	345	360	315	2,177	
C	3	416	372	337	356	413	408	2.302	17,866
	6	561	324	413	318	451	465	2,532	
	9	491	503	495	352	307	428	2,576	
	12	550	574	380	399	355	439	2,697	
	15	317	455	460	332	369	433	2,366	
	18	510	383	468	385	383	450	2,579	
	24	401	507	461	424	479	542	2,814	
D	3	399	325	257	267	318	365	1,931	17,216
	6	742	376	379	473	414	387	2,771	
	9	601	430	490	379	416	318	2,634	
	12	384	719	598	390	309	360	2,760	
	15	512	370	348	372	324	333	2,259	
	18	418	603	374	420	309	309	2,433	
	24	510	351	576	337	342	312	2,428	
Totals		12,651	11,686	11,022	10,065	10,217	10,452		66,093

TABLE 9.—*Total yields in grams for varieties and treatments, second crop, 1933.*

Variety	Grams of seed per row							Totals	Average
	3	6	9	12	15	18	24		
A	1,822	2,239	2,447	2,574	2,709	2,521	2,437	16,749	398.79
B	1,348	1,731	2,271	2,246	2,180	2,309	2,177	14,262	339.57
C	2,302	2,532	2,576	2,697	2,366	2,579	2,814	17,866	425.38
D	1,931	2,771	2,634	2,760	2,259	2,433	2,428	17,216	409.90
Totals	7,403	9,273	9,928	10,277	9,514	9,842	9,856	66,093	
Average	308	386	414	428	396	410	411		393.41

TABLE 10.—*Analysis of variance of data in Tables 8 and 9.*

Variation due to	D.F.	Sum of squares	Mean squares	½ log$_e$	z	P
Blocks	5	177066.33872	35593.26774	—	—	—
Varieties	3	177311.77972	59103.92657	2.04800	1.18217	.01
Treatments	6	227336.78572	37889.46428	1.80401	.93818	.01
Interaction between varieties and treatments	18	107978.92828	5998.82934	.89580	—	—
Error	135	762802.82828	5650.39132	.86583	—	—
Totals	167	1453396.66072				

From Table 10 it is again apparent that there is no significant difference in the interactions between varieties and treatments, but that there are significant differences between varieties and treatments. The results are summarized in Tables 11 and 12.

TABLE 11.—*Summary of yields for varieties, second crop, 1933.*

Yield	Varieties				Mean	S.E.
	A	B	C	D		
Av., gr.	398.78	339.57	425.38	409.90	393.41	11.5988
Per cent.	101.4	86.3	108.1	104.2	100	2.95

Variety B is significantly lower in yield than varieties A, C, and D.

TABLE 12.—*Summary of yields for treatments, second crop, 1933.*

Yield	Grams of seed per row							Mean	S.E.
	3	6	9	12	15	18	24		
Av., gr.	308	386	414	428	396	410	411	393	15.344
Per cent.	78.4	98.2	105.3	108.9	100.8	104.3	104.6	100	3.904

Here, again, the 3-gram rate gives the lowest yield and there is no significant difference between the 6-gram rate and those above 6 grams.

INTERPRETATION OF RESULTS

The three crops including eight varieties show that the 6-gram rate per 14-foot row, with the rows spaced 1½ feet apart, gives as good a yield as the 12- or 24-gram rate of seeding. Based on these results for general farming, one can safely use a 30-pound[4] per acre seeding rate instead of 60 or 120 pounds, provided the rows are 1½ feet apart. If the rows are to be kept 1 foot apart, a seeding rate of 40 to 50 pounds per acre would suffice in place of 80 to 100 or 160 to 200 pounds

For experimental planting it is not necessary for one to take the time to weigh the seed very accurately, but rather one can take a measured quantity of seed. This will save much time and labor, especially if the number of rows is very large, say 10,000 or more, without detracting from the value of the experiment

EFFECT OF VARYING NUMBER OF PLANTS PER HILL

The current method of sowing rice in vogue in all parts of China is that of transplanting, while the direct-planting method is commonly used by experiment stations However, Love (3) suggested that the transplanting method should also be practiced in the advanced test for the reason that varieties may differ in their response to various methods of planting

From the experimental standpoint the hardest work in transplanting is to count the number of seedlings for each hill as is usually done by most of the rice experiment stations in China An effort was made, therefore, to determine (a) whether it is absolutely necessary to count the seedlings in transplanting, and (b) whether the same number of seedlings per hill increases the precision of the results. Obviously, however, the counting of the seedlings would be impracticable in experiments where the number of rows runs into several thousand or more.

RESULTS OF FIRST CROP, 1932

In this experiment the rows were 14 feet long and 1½ feet apart, with 25 hills in each row. The treatments included 2, 3, 4, 5, 7, 9, 12, and 20 seedlings per hill. The planting plan and yields are given in Table 13, the treatment being indicated by the lower figure and the average yield of a 5-row plat by the upper figure in each group. The calculated results are summarized in Table 14.

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[4]The seeding rate per acre for the conditions of this experiment may be calculated as follows:

14 ft. × 1.5 ft. = 21 square feet
43,560 sq. ft. ÷ 21 sq. ft. = 2,074 rows
6 grams × 2,074 rows = 12,444 grams
12,444 grams ÷ 453.6 grams = 27.43 lbs., or the rate per acre on the basis of 6 grams per row.

TABLE 13.—*Planting plan and yields in grams of plats in six blocks, first crop, 1932.**

Block I				Block II				Block III			
228	96	290	190	227	239	299	110	270	302	250	310
12	2	20	5	7	5	20	2	9	12	5	20
206	205	283	256	331	232	331	273	364	244	180	300
9	3	4	7	12	4	9	3	7	3	2	4
Block IV				**Block V**				**Block VI**			
226	313	258	325	328	307	303	303	402	225	369	301
3	20	5	9	12	9	4	2	12	2	9	5
179	214	131	297	249	242	242	368	353	337	300	300
4	7	2	12	7	5	3	20	4	20	7	3

*Upper figures represent yields, lower figures number of plants per hill.

TABLE 14.—*Summary of yields, first crop, 1932.*

Yield	Number of plants per hill								Mean	S.E.
	2	3	4	5	7	9	12	20		
Av., gr. .	209	298	330	296	322	362	378	383	322	16.2
Per cent	64.9	92.5	102.5	91.9	100.0	112.4	117.4	118.9	100	5.03

Two plants per hill gave the lowest yield. There was no significant difference between 3, 4, 5, and 7; 4, 7, 9, and 12; and 9, 12, and 20 plants per hill. The results were quite variable, but it is obvious that 9 plants per hill and above gave no significant differences in the final yield.

RESULTS OF FIRST CROP, 1933

In this trial the same plan was followed as in 1932, but three varieties (A, B, and C) were used instead of one variety. There were eight treatments as in 1932, but the rate of 2 seedlings per hill was omitted and a rate of 15 seedlings per hill added. Thus, there were three varieties, each with eight treatments, 3, 4, 5, 7, 9, 12, 15, and 20 plants per hill, giving 24 different plats in each of the six blocks. This made a total of 144 plats or 720 rows for the experiment.

TABLE 15.—*Yields in grams, first crop, 1933.*

Varieties	Number of plants per hill								Total	Average
	3	4	5	7	9	12	15	20		
A	2,037	2,159	2,322	2,343	2,472	2,746	2,737	2,649	19,462	405
B	2,076	1,900	2,139	2,195	2,221	2,411	2,500	2,511	17,953	374
C	1,920	2,109	2,400	2,431	2,514	2,408	2,458	2,571	18,811	392
Total	6,033	6,165	6,861	6,969	7,207	7,565	7,695	7,731	56,226	—
Average	335	342	381	387	400	420	427	429	——	390.46

The detailed planting plan of the three varieties and eight treatments after randomization is shown in Diagram 4. The yields and analysis of variance are shown in Tables 15 and 16, respectively.

TABLE 16.—*Analysis of variance of data in Table 15.*

Variation due to	D.F.	Sum of squares	Mean square	½ Log$_e$	z	P
Blocks.....	5	182143.333	36428.666	—	—	—
Varieties. .	2	20988.375	10494.187	1.17519	.97270	.01
Treatments	7	168092.86	24013.27	1.58923	1.38674	.01
Interaction between varieties and treatments. . . .	14	23081.848	1648.7034	.25008	.04759	—
Error. . . .	115	172430.334	1499.3942	.20249	—	—
Total. . .	143	566736.75				

The analysis of variance shows that there are no significant differences due to interactions, but that there are significant differences between varieties and treatments. The results are summarized in Tables 17 and 18.

TABLE 17.—*Summary of yields in grams for varieties, first crop, 1933.*

Yield	Varieties			Mean	S.E.
	A	B	C		
Av., gr... .	405.4	376	390	390.46	5.589
Per cent . .	103.8	96.3	99.9	100	1.431

Variety A is a significantly higher yielder than varieties B and C.

TABLE 18.—*Summary of yields in grams for treatments, first crop, 1933.*

Yield	Number of plants per hill								Mean	S.E.
	3	4	5	7	9	12	15	20		
Av., gr..... . .	335	342	381	387	400	420	427	429	390.46	9.13
Per cent .	85.8	87.6	97.6	99.1	102.4	107.6	109.3	109.9	100	2.34

No significant differences are found between treatments 3 and 4; 5, 7, and 9; and 12, 15, and 20 plants per hill, respectively.

RESULTS OF SECOND CROP, 1933

In this trial three different varieties, A, B, and C, were used, each with nine treatments, *viz.*, 3, 4, 5, 7, 9, 12, 15, 20, and 25 plants per hill, making 27 different plats per block. These were replicated and randomized in six blocks, giving 162 plats or 810 rows. The planting plan is shown in Diagram 5, and the yields and analysis of variance are given in Tables 19 and 20, respectively.

Block V								Block VI							
B-4 B-3 C-9	C-20 A-7 B-15	B-9 C-5 A-12	A-15 C-4 A-3	B-12 A-9 C-7	A-4 C-15 B-20	B-5 C-3 A-5	B-7 A-20 C-12	C-3 A-9 B-5	B-20 B-12 C-15	A-7 C-7 A-3	B-15 B-4 A-20	C-4 A-12 B-7	C-5 B-3 C-20	A-15 C-9 A-5	C-12 B-9 A-4
Block III								Block IV							
C-12 A-4 B-20	B-3 C-15 A-12	C-5 B-9 C-7	B-7 C-20 B-4	C-9 A-5 A-3	A-15 C-4 B-12	B-5 A-7 A-9	A-20 C-3 B-15	B-12 A-7 B-20	C-3 B-4 A-15	A-5 A-3 C-9	C-15 A-9 B-5	A-4 C-12 B-15	B-3 B-7 A-12	B-9 C-4 C-20	A-20 C-7 C-5
Block I								Block II							
C-5 B-15 A-4	A-20 C-3 B-7	A-3 A-5 C-9	B-12 B-20 A-15	A-9 C-4 B-3	C-7 B-9 A-12	C-12 C-15 B-4	B-5 A-7 C-20	B-15 A-4 C-9	C-7 B-3 A-12	A-20 C-15 B-7	C-5 B-9 C-4	A-3 B-20 A-15	B-4 A-5 B-12	C-20 A-7 C-3	A-9 C-12 B-5

DIAGRAM 4.—Plan of planting, first crop, 1933. Letters indicate varieties; numerals are number of plants per hill.

Block V									Block VI								
A-9 B-3 C-12	B-5 C-9 A-15	C-7 A-25 B-4	A-20 B-7 C-25	B-12 C-20 A-3	C-15 A-5 B-9	A-4 B-15 C-5	B-25 C-4 A-7	C-3 A-12 B-20	A-5 B-9 C-7	B-15 C-12 A-4	C-9 A-3 B-25	A-12 B-20 C-15	B-3 C-25 A-9	C-20 A-7 B-5	A-25 B-4 C-3	B-7 C-5 A-20	C-4 A-15 B-12
Block III									Block IV								
A-3 B-7 C-15	B-12 C-25 A-5	C-20 A-4 B-9	A-7 B-15 C-3	B-25 C-5 A-12	C-4 A-9 B-20	A-15 B-3 C-7	B-5 C-12 A-25	C-9 A-20 B-4	A-7 B-3 C-15	B-5 C-25 A-12	C-9 A-20 B-4	A-15 B-7 C-3	B-12 C-5 A-25	C-20 A-4 B-9	A-3 B-15 C-7	B-25 C-12 A-5	C-4 A-9 B-20
Block I									Block II								
A-15 B-7 C-3	B-12 C-5 A-25	C-9 A-4 B-20	A-3 B-15 C-7	B-25 C-12 A-5	C-20 A-9 B-4	A-7 B-3 C-15	B-5 C-25 A-12	C-4 A-20 B-9	A-12 B-5 C-25	B-20 C-4 A-9	C-3 A-7 B-15	A-25 B-12 C-5	B-4 C-9 A-20	C-7 A-15 B-3	A-5 B-25 C-12	B-9 C-20 A-4	C-15 A-3 B-7

DIAGRAM 5.—Planting plan, second crop, 1933. Letters indicate varieties and figures number of plants per hill.

TABLE 19.—*Yields in grams, second crop, 1933.*

Variety	Number of plants per hill									Total	Av.
	3	4	5	7	9	12	15	20	25		
A	2,788	2,960	3,032	2,991	3,057	3,001	2,907	2,987	3,042	26,765	496
B	2,578	2,780	2,712	2,817	2,888	2,820	2,856	2,852	2,932	25,235	467
C	2,752	2,948	2,880	2,967	3,009	2,994	2,920	3,061	2,912	26,443	490
Total	8,118	8,688	8,624	8,775	8,954	8,815	8,683	8,900	8,886	78,443	---
Average	451	483	479	487	497	490	482	494	494		484

TABLE 20.—*Analysis of variance of data in Table 19*

Variation due to	D F	Sum of squares	Mean squares	½ Log$_e$	z	P
Blocks	5	20835.351	4167.070	———	———	—
Varieties	2	24097.888	12048.944	2.39574	1.46438	.01
Treatments	8	27812.444	3476.555	1.77423	.84297	.01
Interaction between varieties and treatments	16	6777.668	423.604	.72180	--	—
Error	130	83952.149	644.2473	.93126		
Total	161	163275.5				

Here, again, there are no significant differences due to interactions, but differences among varieties and treatments are highly significant. The results are summarized in Tables 21 and 22

TABLE 21.—*Summary of yields for varieties, second crop, 1933.*

Yield	Varieties			Mean	S.E.
	A	B	C		
Av., gr.	496	467	490	484	3.45
Per cent	102.5	96.5	101.2	100	.713

Varieties A and C are significantly higher yielders than variety B.

TABLE 22.—*Summary of yields for treatments, second crop, 1933.*

Yield	Number of plants per hill									Mean	S.E.
	3	4	5	7	9	12	15	20	25		
Av., gr...	451	483	479	487	497	490	482	494	494	484	5.98
Per cent..	93.2	99.8	99.0	100.1	102.7	101.2	99.6	102.1	102.1	100	1.23

The rate of three plants per hill gave the lowest yield, but the results from 4 to 25 plants per hill showed no significant differences.

CONCLUSION AND DISCUSSION

The results of the three experiments indicate that the first crop needs more plants per hill than does the second crop, and that it is

sufficient to have 9 or 12 plants per hill for the first crop and 4 or 5 plants per hill for the second crop. Any excess in number of plants per hill gave no advantage. The results of the second crop are further confirmed in the third experiment of this group.

COMBINED EFFECT OF NUMBER OF PLANTS PER HILL AND DISTANCE BETWEEN HILLS

The second experiment of this group was confined to a study of the number of plants per hill, while in the present experiment the study was extended to the relation between number of plants per hill and the distance between hills. The arrangement of plats is shown in Diagram 6.

Block IX						Block X					
12-9 18-12 7-4 18-4 9-18	12-6 7-9 12-12 12-15 7-18	7-15 18-15 7-6 5-12 12-4	7-12 5-9 5-18 9-4 9-6	18-6 18-18 5-6 9-12 9-15	12-18 18-9 5-15 5-4 9-9	12-12 18-4 7-15 7-4 9-9	7-12 7-18 5-9 5-6 9-18	12-18 7-6 12-9 12-4 9-6	18-9 5-18 5-4 9-15 18-6	18-12 12-6 18-18 5-15 18-15	5-12 7-9 12-15 9-4 9-12
Block VII						**Block VIII**					
5-4 12-9 7-18 18-18 9-12	7-6 18-12 9-4 5-9 12-15	9-18 15-15 12-6 7-12 18-4	12-12 7-4 18-9 9-15 5-18	18-15 9-6 5-12 12-4 7-9	9-9 12-18 7-15 18-6 7-6	12-4 18-15 5-12 7-18 9-12	7-12 9-18 12-6 18-12 5-6	18-18 5-4 7-15 9-6 12-18	9-15 12-12 18-9 5-15 7-9	5-9 7-6 9-4 12-9 18-4	18-6 9-9 5-18 7-4 12-15
Block V						**Block VI**					
5-6 5-18 18-12 9-6 9-4	18-9 18-4 5-4 7-4 12-9	7-9 18-6 7-18 9-18 18-18	7-6 9-12 5-9 12-4 9-9	5-15 12-6 18-15 9-15 12-18	7-12 7-15 12-12 5-12 12-15	5-4 7-15 9-12 12-18 18-6	12-12 18-18 5-18 7-4 9-15	7-6 9-4 12-15 18-12 5-9	18-15 5-12 7-9 9-6 12-4	9-9 12-6 18-4 5-15 7-12	7-18 18-9 5-6 12-9 9-18
Block III						**Block IV**					
9-9 12-9 7-4 5-18 18-18	12-12 9-4 18-4 9-18 7-12	9-12 9-15 12-6 9-6 7-15	18-6 12-15 7-18 7-6 12-4	18-12 18-15 7-9 5-15 5-4	18-9 5-12 5-6 5-9 12-18	5-12 18-15 18-12 7-9 18-6	18-9 5-18 7-12 5-6 7-4	12-9 9-18 5-15 9-9 9-12	7-18 5-9 12-18 5-4 12-15	18-18 12-6 9-6 12-4 18-4	7-6 9-4 9-15 7-15 12-12
Block I						**Block II**					
9-9 5-18 12-4 7-18 18-9	12-18 7-4 18-6 9-12 5-12	18-15 9-6 5-9 12-15 7-15	5-4 12-9 7-12 18-4 9-18	7-6 18-12 9-15 5-6 12-6	12-12 5-15 18-18 7-9 9-4	18-12 5-12 7-18 9-12 12-18	7-4 9-18 12-12 18-4 5-9	12-9 18-9 5-4 7-9 9-15	5-15 7-15 9-9 12-15 18-6	9-6 12-6 18-15 5-6 7-12	5-18 9-4 7-6 18-18 12-4

DIAGRAM 6.—Plan of planting, second crop, 1933. See text for explanation of figures.

There were 10 blocks of 30 plats each with five rows in each plat, giving a total of 300 plats and 1,500 rows. The rows were 15 feet long and 1½ feet apart. In each of the blocks two different treatments were brought together, *viz.*, number of plants per hill, i. e., 5, 7, 9, 12, and 18 plants, and distance between the hills in a row, i. e., 4, 6, 9, 12, 15, and 18 inches. In Diagram 6 the number of plants is repre-

Distance between plants, in.	Blocks I	II	III	IV	V	VI	VII	VIII	IX	X	Treatment totals	Grand total
					5 Plants per Hill							
4	447	492	438	447	515	397	337	345	422	503	4,343	
6	512	436	391	399	393	323	360	334	409	434	3,991	
9	462	438	367	413	443	361	342	337	385	386	3,934	
12	519	388	280	374	438	278	255	304	374	314	3,524	
15	363	318	326	304	383	296	251	288	317	380	3,226	
18	309	296	304	293	288	240	280	277	266	322	2,875	21,893
					7 Plants per Hill							
4	446	414	442	472	473	395	306	399	397	412	4,156	
6	423	433	460	386	458	354	290	354	341	447	3,946	
9	463	467	371	395	428	352	369	363	317	312	3,837	
12	453	364	418	353	423	317	325	262	331	317	3,563	
15	492	364	348	303	327	265	312	340	287	372	3,410	
18	376	329	306	314	388	260	245	276	271	290	3,055	21,967
					9 Plants per Hill							
4	497	477	432	470	412	370	348	353	438	475	4,272	
6	440	450	420	340	396	399	288	379	374	407	3,893	
9	351	433	374	392	390	312	255	317	318	346	3,488	
12	450	439	347	398	383	304	371	341	392	385	3,810	
15	396	445	327	345	395	326	282	298	312	406	3,532	
18	446	331	377	343	300	304	194	230	312	320	3,157	22,152
					12 Plants per Hill							
4	465	493	447	411	416	396	354	289	425	439	4,135	
6	522	428	462	454	421	311	354	367	353	439	4,111	
9	440	398	422	424	436	368	330	367	311	444	3,940	
12	384	412	368	378	398	359	230	285	319	283	3,416	
15	428	423	360	386	373	313	292	340	343	359	3,617	
18	298	427	328	338	324	355	272	299	300	290	3,231	22,450
					18 Plants per Hill							
4	545	532	442	452	463	380	417	437	447	435	4,550	
6	504	450	391	444	431	412	321	303	323	435	4,014	
9	494	386	365	422	450	321	338	334	399	339	3,848	
12	418	390	358	369	414	313	292	305	331	372	3,562	
15	367	459	344	372	362	279	238	255	317	368	3,261	
18	356	380	384	353	361	331	369	329	345	407	3,615	22,850
Total..........	13,066	12,392	11,399	11,544	12,082	9,991	9,217	9,707	10,476	11,438	111,312	

sented by the first number in each group and the distance apart by the number following. Thus, in block 1 in the lower left group, 18-9 means 18 plants per hill at a distance of 9 inches. There are 30 combinations in each block, each plat representing a different combination.

The yields are shown in Tables 23 and 24 and the analysis of variance is given in Table 25.

TABLE 24.—*Summary of yields given in Table 23.*

Number of plants per hill	Distance between plants, inches						Total	Average
	4	6	9	12	15	18		
5	4.343	3.991	3.934	3.524	3.226	2,875	21,893	364.9
7	4.156	3.946	3.837	3.563	3.410	3.055	21.967	366.1
9	4.272	3.893	3.488	3.810	3.532	3.157	22.152	366.9
12	4.135	4.111	3.940	3.416	3.617	3.231	22.450	374.0
18	4.550	4.014	3.848	3.562	3.261	3.615	22,850	380.8
Total	21.456	19.955	19.047	17.875	17.046	15.933	111.312	
Average	429.1	399.1	380.9	357.5	340.9	318.7	371.04	

TABLE 25.—*Analysis of variance of data in Table 24.*

Variation due to	D.F.	Sum of squares	Mean squares	½ Log$_e$	z	P
Blocks..	9	466506.186	51830.2070	5.42785	1.88992	.01
Distance	5	404643.520	80928.7040	5.65066	2.11273	.01
Number of plants	4	10272.8866	2568.2216	3.92544	.38751	--
Interaction between distance and number of plants	20	67266.1134	3363.3057	4.06028	.52235	.01
Error.	261	308916.8140	1183.1009	3.53703	--	-
Total	299	1257605.5200				

There is no significant difference between the number of plants used in the hill. This agrees with the results obtained from the second crop in 1932, in the second experiment in this group.

Distance between plants and interactions between distance and number of plants per hill show a very highly significant difference with P = .01. The results are summarized in Tables 26 and 27.

TABLE 26.—*Summary for distance between plants.*

Yield	Distance between plants, inches						Mean	S.E.
	4	6	9	12	15	18		
Av., gr........	429.1	399.1	380.9	357.5	340.9	318.7	371.04	4.864
Per cent.......	115.6	107.6	102.4	96.3	91.8	85.9	100	1.31

The differences between each of these distances are significant, and the closer the distance the higher is the yield.

TABLE 27. *Summary for interactions between distance and number of plants.*

Yield	Distance between plants, inches						Mean
	4	6	9	12	15	18	
			5 Plants per Hill				
Total, gr	4343	3991	3934	3524	3226	2875	——
Av., gr	434.3	399.1	393.4	352.4	322.6	287.5	——
Per cent	117.06	107.57	106.04	94.99	86.95	77.49	——
			7 Plants per Hill				
Total, gr	4156	3946	3837	3563	3410	3055	——
Av., gr	415.6	394.6	383.7	356.3	341.0	305.5	——
Per cent	112.22	106.36	103.43	96.04	91.94	82.34	——
			9 Plants per Hill				
Total, gr	4272	3893	3488	3810	3532	3157	——
Av., gr	427.2	389.3	348.8	381.0	353.2	315.7	——
Per cent	115.15	104.93	94.02	102.69	95.20	85.09	——
			12 Plants per Hill				
Total, gr	4135	4111	3940	3416	3617	3231	——
Av., gr	413.5	411.1	394.0	341.6	361.7	323.1	——
Per cent	111.46	110.81	106.20	92.07	97.49	87.09	——
			18 Plants per Hill				
Total, gr	4550	4014	3848	3562	3261	3615	——
Av., gr	455.0	401.4	384.8	356.2	326.1	361.5	371.04
Per cent	122.64	108.19	103.72	96.01	87.90	97.44	100%

$$\text{S. E. of mean of 10 plats} = \frac{34.3948}{\sqrt{10}} = 10.877 \text{ or } 2.932\%.$$

Three times the standard error (3 x 2.932) equals 8.796 or approximately 9%. This figure can be used as the level to measure the significance of differences in this table.

Examining Table 27 more closely, it is seen that if one takes any of the distances between plants and compares the figures, starting from the top and going to the bottom, for the various numbers of plants per hill, one finds that most of the differences are insignificant. Also, if one takes any of the numbers of plants per hill and compares the figures, starting from the left and going to the right for each distance, one finds that most of the differences are significant.

These relationships can be shown much more clearly by the use of regression lines. The formula used here is $Y = a + b\,(x - \bar{x})$. The slopes in Fig. 1 are very steep and those in Fig. 2 are practically parallel to the base line, except those for 4 and 18 inches, but differ remarkably in their height.

In Fig. 1 we find that the slope is greatest for five plants. Taking the least distance, 4 inches, there is practically no difference in yield between 5 and 18 plants. If we use the largest distance, 18 inches, we find the yield of 18 plants is much higher than that for 5 plants.

In Fig. 2 we find the same is true, the yield for 18 inches with 5 plants being much lower than the rest, but when the number of plants is increased to 18 the yield is increased to as high as, or even higher than, that for 12 inches. This shows that if we use a wide distance between hills we must use a large number of plants in order to get a fairly high yield.

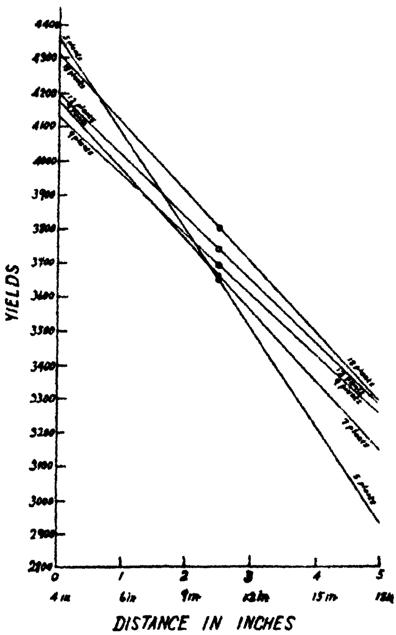

FIG. 1.—Regression of yield on distance between hills.

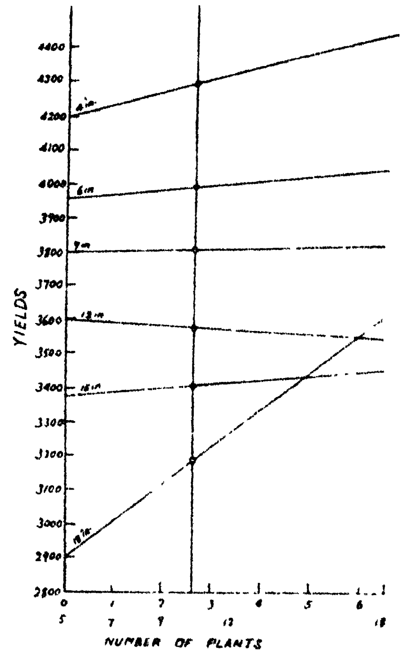

FIG. 2.—Regression of yield on number of plants per hill.

DISCUSSION AND CONCLUSIONS

The same experiment has been repeated with the second crop in 1934 and the first and second crops in 1935 and slightly different results obtained. A more complete discussion will be available in the near future, but the present experiment brings out the following points:

1. Differences due to distances are significant, i. e., the closer the distance the higher is the yield.

2. Differences due to the number of plants per hill are insignificant. For instance, there was no significant difference between the yields when five plants per hill were used or when 18 plants per hill were used. This agrees with the results from the second experiment.

3. Interactions between distance and number of plants are also significant. In order to get a fairly high yield, the greater the distance between the hills the larger should be the number of plants per hill.

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PASTURE RENOVATION IN RELATION TO POPULATIONS OF WHITE GRUBS[1]

R. F. FUELLEMAN AND L. F. GRABER[2]

WITH the frequency and intensity of dry weather during the past nine years, permanent pastures and corn fields have been widely and severely injured by white grubs, larvae of June beetles (*Phyllophaga* spp.). Particularly have these insects become agents of destruction of major importance in southern and western Wisconsin. Here, the topography is such that over 45% of the land is devoted to permanent bluegrass pastures, thus providing an extensive egg-laying area for these insects. Not only have the larvae caused great damage to pasture grasses and to the corn and small grains of that area, but the adult beetle, through its cyclic defoliations, has probably contributed to the death of many oak trees, particularly *Quercus alba*, and *Quercus macrocarpa*, which are the dominant species of this region.

Damage to the permanent pastures, however, is of far greater economic importance. This is especially true when it occurs in seasons of drouth. When rainfall is plentiful and other environmental factors are favorable for vegetative growth, the grubs continue their destructive activity, but the results are not as apparent, for the regenerative capacity of the grasses tends to minimize and mask the injury. This is well shown by the work of Graber, Fluke, and Dexter (6)[3], where under controlled conditions the productivity of bluegrass (*Poa pratensis*), with high food reserves, was reduced from 7 to 23%, as a result of the feeding of white grubs on the rhizomes of such grass This occurred when the moisture supply was maintained at optimum levels for the growth of the grass. A loss of 33 to 37% in productivity occurred with comparable bluegrass grown with a deficient moisture supply. With bluegrass low in reserve foods the reduction in productivity from grub injury was much more severe (Fig. 1). Under conditions of optimum moisture, the losses in productivity ranged from 53 to 77%, and with deficient moisture from 70 to 88%. Liberal fertilization in the above trials reduced the intensity of injury except where rapid and dense accumulations of leaf growth inhibited rhizome growth and the regenerative capacity of the grass to a marked degree. These investigators conclude, "that the injury from white grubs is lessened when conditions favor the quantitative development of subterranean growth of bluegrass and especially when such factors of the environment augment the regenerative activity of the grass during the feeding period of the insect."

That June beetles, adult forms of white grubs, exercise what is probably a vegetational selectivity in egg deposition has been demon-

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[3]Figures in parenthesis refer to "Literature Cited", p. 196.

strated by Fluke, Graber, and Koch (1), who investigated the populations of white grubs in 45 areas of bluegrass pastures located in southern and western Wisconsin. They found "only one-third the number of grubs in thick sods as occurred in thin sods" of bluegrass pastures. Where pastures had been renovated (4) with sweet clover (*Melilotus alba*) so that at the time of oviposition by June beetles the sweet clover was growing in association with bluegrass (*Poa pratensis*) either in the seedling or second year stages of growth, the grub populations were very low. In five such areas an average of 28,000 grubs per acre was found where sweet clover was abundant during the preceding flights of egg-laying beetles, compared with 148,000 per acre in five adjacent and comparable areas of bluegrass in which sweet clover had not been established. The authors state that, "such densities are accounted for by an adult avoidance of sweet clover as a desirable crop medium for egg laying, since it is assumed that if the eggs were laid in such places they would hatch and the grubs develop."

FIG. 1.- An old bluegrass sod completely killed and severed from its contacts with the soil by the feeding of numerous white grubs on the rhizomes and roots. Photo taken September 17, 1936.

Graber, Fluke, and Koch (2) selected a 6-acre area of an old bluegrass pasture for a further trial on the vegetational selectivity of June beetles in egg deposition. This area was bordered on three sides by white and bur oak trees which provided abundant feed for egg-laying June beetles. The entire area was seeded with long strips of a mixture of bluegrass, timothy, and a leguminous forage alternating with a mixture of bluegrass and timothy. These seedings were made on April 9, 1931. A minor flight of June beetles occurred in May and June that year and a major flight occurred in 1932, with the following subsequent populations of white grubs:

Bluegrass and timothy..................	180,000 grubs per acre
Sweet clover (common biennial white) established in above grasses.............	No grubs found
Bluegrass and timothy..................	120,000 grubs per acre
Mixture of red clover and sweet clover in above grasses........................	No grubs found
Red clover in above grasses.............	40,000 grubs per acre

Bluegrass and timothy	120,000 grubs per acre
Alfalfa and above grasses	40,000 grubs per acre
Alsike clover (poor stand) and above grasses	120,000 grubs per acre
Bluegrass and timothy	140,000 grubs per acre
Ladino clover (poor stand) and above grasses	80,000 grubs per acre
White clover (poor stand) and above grasses	200,000 grubs per acre

Over 70% of the grubs came from eggs laid in 1932 and less than 30% from the eggs laid during the 1931 flight. These data show that sweet clover, alfalfa, and red clover, either in seedling or later stages of growth, reduce white grub populations very effectively when dense growths are present during the beetle flights.

METHODS AND PROCEDURE

In 1934 and 1935, portions of 30 permanent bluegrass pastures in southern and western Wisconsin were renovated with deep-rooted, dry-weather legumes, according to methods described by Graber (4) in which the sods were not plowed but were scarified by disking and other cultivation. This injured but did not eliminate the grasses. It reduced temporarily the competition of the sod and provided soil contacts for the seeds of the dry weather legumes, sweet clover (*Melilotus alba*), alfalfa (*Medicago sativa*), and red clover (*Trifolium pratense*), which were sown shortly after the scarification process was completed. Four of these renovations were less than 2 acres in area, 19 varied from 4 to 8 acres, and 7 ranged from 12 to 33 acres in extent. In order to obtain definite information on the conditions prevailing in these pastures and to amplify the data obtained in previous trials, a large number of randomized counts of white grubs were made in such renovated areas and in adjacent and similar areas of unrenovated bluegrass pasture.

It is the purpose of this paper to present an analysis of the data obtained during the fall of 1935 and the growing season of 1936, and to ascertain the effect of renovation and vegetational cover in pastures on subsequent populations of white grubs.

In making sample counts of white grubs, a wood quadrat, with an area of either 1/20,000 of an acre or one of 2 square feet, was used. A spade and an axe were the only other implements necessary. The quadrat was placed at random on the area, the sod cut either with the spade or the axe, and lifted. The soil for a depth of 6 inches was removed and examined carefully for grubs. Most of the grubs were found in the upper 3 or 4 inches of sod and soil. The sod was cut into smaller pieces and each piece was shaken and carefully inspected. A series of 10 counts was made for each type of vegetational cover. From this the average was computed on an acre basis. The results are presented in Table 1. These results were also analyzed statistically, using the X^2 test of independence or association as shown in Tables 2 and 3.

The pastures in which renovated areas were established in 1934 and 1935 were located in Dane, LaFayette, Iowa, Grant, Richland, Crawford, and Vernon counties of southern and western Wisconsin. Observed estimates of injury sustained by the grasses in the renovated and unrenovated portions of the pastures were made in September, 1936. These estimates were based on the recovery

of the pasture grasses (primarily bluegrass) about 3 weeks after abundant rains had broken the intensive summer drouth. In some instances the grasses were injured by excessive summer heat. This occurred particularly on thinly sodded knolls and such injury was not included in the estimates of grub injury.

RENOVATION AND VEGETATIVE COVER

Fifteen areas of the 30 pastures were renovated with dry weather legumes in 1934 and 15 in 1935 The thin-sodded portions of old bluegrass pastures were chosen for improvement by renovation. The first step in this process (4) is to apply lime and fertilizer where needed for the growth of the dry weather legumes, sweet clover, alfalfa, and red clover. This is immediately followed by disking and other cultivation to scarify the sod where needed to establish soil contacts for leguminous seeds which are sown soon after the sod has been prepared. Immediately prior to such renovation the pasture vegetation consisted primarily of a thin sod of Kentucky bluegrass with an associated growth of seedling ragweeds (*Ambrosia artemisiiafolia*) The remaining unrenovated portions of the pastures were similar except that the sods were, in general, denser and fewer ragweeds were in evidence Specifically was this true of pastures Nos. 12 and 13 (Table 1).

Renovation altered the vegetative cover very considerably. After seeding it consisted of a scarified sod (with much soil exposed) in which a dense growth of seedling dry-weather legumes and weeds (particularly ragweeds) appeared along with a sparse growth of grass. This was true in all cases except No. 30 where only a fair stand of legumes occurred. In their second year of growth the legumes distinctly dominated all other vegetation. On all renovated areas, except Nos. 2, 11, 14, 15, 23, 26, and 27, mixtures of the three dry-weather legumes were established in which sweet clover and alfalfa predominated. In renovated areas of pastures Nos. 2, 11, and 14, alfalfa predominated; in Nos. 23 and 26, red clover; and in No. 26, sweet clover and red clover provided the dominant vegetative cover during the beetle flights.

VEGETATIVE COVER AND GRUB POPULATIONS

Two flights of June beetles took place during the period of these trials. A minor flight (brood C) in May and June of 1934 and a major flight (brood A) occurred during the same months of the following year (5). It is important to bear in mind that the portions of pastures renovated in 1934 (Nos. 1 to 15) were exposed to the egg-depositions of two beetle flights (1934 and 1935), while the portions of pastures renovated in 1935 were exposed to the same flights but the renovations would only affect the grub populations resulting from egg-depositions of the flight of 1935. This situation has had a very definite effect on the subsequent populations of grubs in the renovated areas.

In only 4 out of the 15 areas renovated in 1934 (Table 1) were any grubs found and these at the rate of only 4,000, 6,000, 6,534, and 8,000 per acre. In contrast only one area renovated in 1935 was free of grubs (No. 23), the remaining renovated areas containing 2,178 to

TABLE 1.—*Vegetative cover of renovated and unrenovated portions of old permanent bluegrass pastures and populations of white grubs subsequent to the June beetle flights of 1934 and 1935*

Pasture No.	Date dry weather legumes were seeded	Date of white grub counts	Vegetational cover during beetle flights of 1934 and 1935 and subsequent populations of white grubs						
			Renovated portion			Grub injury observed Sept. 1936	Adjacent portion not renovated		
			Vegetative cover*		Av. No. of white grubs per acre		Vegetative cover*		Av. No. of white grubs per acre	Grub injury observed Sept. 1936
			May-June 1934	May-June 1935			May-June 1934	May-June 1935		
1	June 12, 1923	Oct. 17, 1935	A	B	0	None	E	E	55,757	Slight
2	May 12, 1934	Oct. 4, 1935	A	B	0	None	E	E	152,460	Serious
3	May 12, 1934	Oct. 4, 1935	A	B	0	None	F	F	67,518	Moderate
4	June 11, 1934	Oct. 18, 1935	A	B	0	None	E	E	34,848	Slight
5	May 28, 1934	June 16, 1936	A	B	8,000	Very slight	E	E	220,000	Very serious
6	May 4, 1934	June 17, 1936	A	B	0	None	E	E	142,000	Moderate
7	May 17, 1934	June 16, 1936	A	B	0	None	E	E	232,000	Very serious
8	May 5, 1934	June 16, 1936	A	B	0	None	E	E	126,000	Moderate
9	May 12, 1934	June 10, 1936	A	B	0	None	E	E	154,000	Serious
10	May 8, 1934	Aug. 4, 1936	A	B	4,000	None	E	E	292,000	Very serious
11	May 7, 1934	Aug. 4, 1936	A	B	0	None	E	E	314,000	Very serious
12	May 3, 1934	Oct. 17, 1935	A	B	0	None	F	F	0	None
13	April 30, 1934	June 18, 1936	A	B	0	None	F	F	0	None
14	April 30, 1934	Oct. 4, 1935	C	D	6,534	None	E	E	87,120	Moderate
15	Nov. 22, 1933	Sept. 19, 1936	A	B	6,000	Very slight	E	E	126,000	Very serious

16	June 1, 1935	Oct. 4, 1935	E	A	4,356	None	E	E	172,008	Serious
17	June 3, 1935	June 3, 1936	E	A	10,000	Very slight	E	E	150,000	Serious
18	May 9, 1935	June 4, 1936	E	A	8,000	Very slight	E	E	214,000	Very serious
19	June 7, 1935	June 15, 1936	E	A	14,000	Very slight	E	E	120,000	Serious
20	May 25, 1935	June 16, 1936	E	A	8,000	Very slight	E	E	128,000	Moderate
21	May 16, 1935	June 17, 1936	E	A	8,000	Very slight	E	E	330,000	Very serious
22	May 21, 1935	July 20, 1936	E	A	14,000	Very slight	E	E	168,000	Serious
23	May 21, 1935	July 20, 1936	E	A	0	None	E	E	154,000	Serious
24	May 24, 1935	July 20, 1936	E	A	16,000	Very slight	E	E	320,000	Very serious
25	Nov. 17, 1934	June 11, 1936	E	A	8,000	Very slight	E	E	172,000	Moderate
26	Mar. 14, 1935	June 11, 1936	E	A	74,000	Slight	E	E	106,000	Slight
27	Mar. 14, 1935	June 11, 1936	E	A	30,000	Very slight	E	E	112,000	Moderate
28	Mar. 20, 1935	Oct. 3, 1935	E	A	4,356	None	E	E	156,700	Moderate
29	Mar. 20, 1935	Oct. 3, 1935	E	A	2,178	None	F	F	47,916	Very slight
30	Mar. 20, 1935	Oct. 3, 1935	D	D	8,712	None	E	E	156,700	Moderate

*Types of vegetative cover are as follows:

A. Cultivated bluegrass sod (*Poa pratensis*) with dense seedling growth of dry-weather legumes and seedling ragweeds (*Ambrosia artemisifolia*). Dry-weather legumes are alfalfa (*Medicago sativa*), sweet clover (*Melilotus alba*), and red clover (*Trifolium pratense*) grown in mixture with each other or alone. In all pastures except No. 2, 11, 14, 22, and 25, sweet clover and alfalfa predominated. Red clover provided the dominant vegetative cover in Nos. 22 and 25 and alfalfa in Nos. 2, 11, and 14.

B. Dense second-year growth of dry-weather legumes.

C. Dense seedling growth of small grains and dry-weather legumes.

D. Fair stand of dry-weather legumes and thin stand of Kentucky bluegrass.

E. Thin sod of Kentucky bluegrass and seedling ragweeds.

F. Dense sod of Kentucky bluegrass.

74,000 grubs per acre. Nearly all these grubs came from the egg depositions of 1934 at which time the areas had not been renovated. It is evident, therefore, that where two successive beetle flights occur the renovations preceding both are more effective in reducing grub populations. The marked effect of pasture renovation on grub populations becomes strikingly apparent with the counts of grubs in the adjacent unrenovated areas of bluegrass. Here the populations ranged from 34,848 to 314,000 grubs per acre for the 1934 series (Nos. 1 to 15), except for two pastures (Nos. 12 and 13) where no grubs were found in either the renovated areas or in the dense sods of unrenovated bluegrass. For the 1935 series (Nos. 16 to 30) from 47,916 to 330,000 grubs per acre were found in the unrenovated pastures.

INJURY FROM WHITE GRUBS

The comparative degree of injury sustained in the renovated and unrenovated portions of the 30 pastures were estimated in the fall of 1936. These estimates were made after abundant rains brought about substantial recovery of the bluegrass from its dormant condition during the long period of intense summer heat and drouth. In only 2 out of the 15 renovations of 1934 was any injury apparent (and that very slight), while in the adjacent unrenovated bluegrass (Table 1) there were 5 cases of very severe injury, 2 serious, 4 moderate, 2 slight, and 2 cases of no injury. With the renovations of 1935, there was 1 case of slight injury, 9 of very slight injury, and 5 of no injury. In the adjacent unrenovated pasture there were, in contrast, 3 cases of very serious injury, 5 serious, 5 moderate, 1 slight, and 1 case of very slight injury. In all cases the grass was more vigorous in the renovated areas. The degree of injury, however, did not always correlate with the number of grubs and this is accounted for, in part, by the variability in fertility, soil depth, and previous grazing treatment of the pastures.

DISCUSSION

The factors which are operative in reducing populations of white grubs in renovated pastures have not been determined in this study. It seems very probable that the legumes, sweet clover, alfalfa, and red clover have a marked repelling influence on the egg depositions of the June beetle. While other features of the renovation process, such as liming, fertilization, and the cultivation of the sod with the exposure of the soil and partial destruction of the grass, may be inhibiting factors in egg deposition, they appear, as such, to be of secondary importance. In many of these trials portions of the renovated areas were fertilized with phosphate and potash fertilizer. This treatment had no direct effect on the grub populations. Many of the areas were limed and in a number, the legumes were successfully established without lime. In both cases the legumes were equally effective in reducing the populations of the insect. In one trial (1931) the sod was cultivated but legumes were seeded only on long narrow plats which alternated with cultivated plats in which legumes were not sown. Where the three legumes, sweet clover, alfalfa, and red clover were established the populations of white grubs were greatly reduced, while cultivation alone (without seeding legumes) proved to

be ineffective. The cultivation of the sod may have some influence on egg-laying, but the reduction in grub populations seems to rest primarily on the density of the growth of the dry weather legumes. Observations, not fully reported in this paper, indicate that thick stands are much more effective than sparse or thin stands.

Aside from the probable repellant action of dry weather legumes, there still remains the remote possibility of the failure of eggs to hatch or to develop into grubs when laid in soil producing dense growths of such legumes. This may obtain, but Graber and Fluke (5) have shown that white grubs will feed on the roots of alfalfa. In subsequent observations grubs have been found to feed on the roots of sweet clover and red clover destroying portions of the phloem and often severing the entire root. This has happened frequently when the underground parts of grasses were sparse and when at the time of seeding dry-

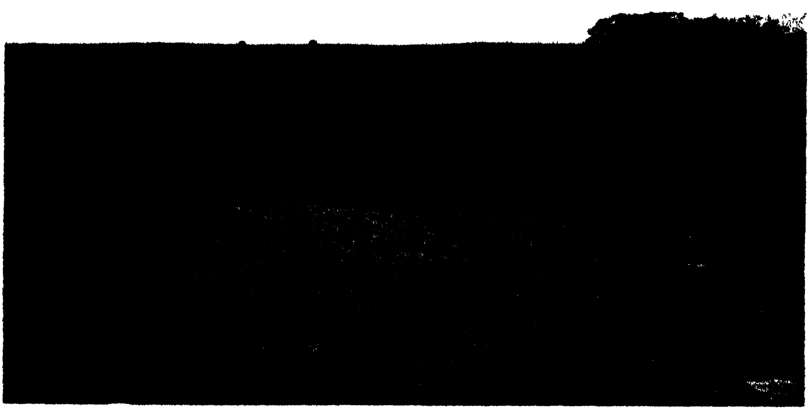

FIG. 2.—On August 4, 1936, over 90% of the grass of the unrenovated bluegrass pasture (foreground) was killed by the white grubs present at the rate of 292,000 per acre, while the grass of the adjacent pasture (background), which was renovated in 1934 with alfalfa, red clover, and sweet clover, showed no injury and was infested with grubs at the rate of only 4,000 per acre. Both bluegrass pastures have been grazed annually for more than 45 years. Photo taken October 20, 1936.

weather legumes, the larvae were already present in the soil. Such observations would lead one to feel that the roots of these legumes are not particularly repulsive or injurious to the grubs. Furthermore, grubs have been found abundantly where thin stands of sweet clover, alfalfa, and red clover prevailed in bluegrass, indicating that the eggs may have hatched in close proximity to these legumes. Regardless of the factors which may be involved, it is clear in these and in previous studies that renovation does effectively reduce the grub populations and their injury (Fig. 2). This holds true whether the dry weather legumes have been established through the process of renovation or by the process of plowing and seeding with a nurse crop as is customary with cropped land in Wisconsin.

The reduction in grub populations of pastures after renovation is

not temporary, but seems to be effective for long periods of time especially when renovated pastures are not grazed excessively. In 1929, 4 acres of a thinly sodded weedy pasture were renovated with sweet clover. In 1930 the plot was grazed so that the sweet clover produced an abundance of seed which fell to the ground. In 1931, and annually thereafter, rather dense volunteer growths of sweet clover have appeared in the renovated portion of this pasture. Grub counts made on this area on October 4, 1935, revealed the presence of 23,950 grubs per acre compared with 117,612 grubs per acre in the adjacent bluegrass which had not been renovated.

In another instance, alfalfa seed was sown in scarified sod in 1931 resulting in the establishment of a thick stand of alfalfa and a dense sod of bluegrass in which the alfalfa maintained itself effectively until 1936. In counts made on this area on October 4, 1935, no grubs were found, but in the unrenovated bluegrass they were present at the rate of 156,700 per acre. Fields of corn have been observed where a portion was grown on the thin, old grassy alfalfa sods and the remainder on adjacent timothy and bluegrass sods. Only the corn grown on the latter sods was badly injured. These along with many other striking observations indicate that dry weather legumes may be effective for several years in reducing grub populations on the areas where they are properly established. These plants are not only valuable for supplying succulent pasturage and for inhibiting egg depositions of June beetles, but their associated growth with bluegrass builds up the density and the productivity of thin grass sods which make them undesirable for the egg depositions of June beetles.

STATISTICAL ANALYSIS

A statistical analysis of the data is included to evaluate the differences occurring between the variables involved (Tables 2 and 3). The X^2 test of independence or association was used in making this analysis, using Fisher's tables of X^2 for value of P.

X^2 is calculated from Table 2, according to Goulden's (3) formula. Populations of white grubs at a rate of 0 2 grubs per sample are not considered injurious to the vegetation and as such are placed within one group. Those sample counts containing 3 or more grubs per sample were considered injurious to the vegetation and in this analysis are grouped as a unit. The significance of the differences between the variables in all cases is large and the odds are very great that these differences are not due to chance alone

The calculated differences between the number of grubs in the pasture areas renovated in 1934 and in the adjacent unrenovated bluegrass gives a very significant value of 213.0 for X^2 in which case the P value at the 1% point for 3 degrees of freedom (Table 3) is 11.341. By the same criteria, the X^2 of 237.2 for the difference between the number of grubs in the pastures renovated in 1935 and in the unrenovated portions of the adjacent pastures, is highly significant. The X^2 value for differences between the pastures renovated in 1934 and those renovated in 1935 is 8.21. In this latter instance the value of X^2 is based on 1 degree of freedom and accordingly the value at the 1% point is 6.635. While this value of X^2 is not as large

TABLE 2.—*Number of white grubs in 1934 and 1935 renovated pastures and portions of adjacent unrenovated bluegrass pastures.*

Number of grubs per sample	Pastures renovated in 1934, and portions of adjacent bluegrass pastures: Type of vegetative cover and number of samples in each†					Pastures renovated in 1935, and portions of adjacent bluegrass pastures: Type of vegetative cover and number of samples in each†				
	B	D	E	F	Totals	A	D	E	F	Totals
0-2*	140	10	22	25	197	132	10	6	4	152
3-5	0	0	32	3	35	6	0	29	6	41
6-10	0	0	51	2	53	1	0	71	0	72
11-15	0	0	11	0	11	1	0	17	0	18
16-20	0	0	8	0	8	0	0	10	0	10
21-25	0	0	4	0	4	0	0	7	0	7
26-35	0	0	2	0	2	0	0	0	0	0
Totals	140	10	130	30	310	140	10	140	10	300

*Group 0-2 not considered injurious to vegetation, the remaining groups (3-35) are injurious.
†Vegetative covers designated by letter are explained in Table 1.

TABLE 3.—*X^2 tests of independence or association*

Data compared	Degrees of freedom	X^2	P = 1%
Renovated in 1934 and unrenovated pastures	3	213.0	11.341
Renovated in 1935 and unrenovated pastures	3	237.2	11.341
Renovated in 1934 and renovated in 1935	1	8.21	6.635

as the value obtained in the two preceding cases, it is sufficiently large to show that the differences are not due to chance alone.

SUMMARY

The establishment of dry-weather legumes (alfalfa, sweet clover, and red clover) in permanent bluegrass pastures without plowing is termed renovation, in this paper. Where this was practiced in portions of 30 old bluegrass pastures in 1934 and 1935, the populations of white grubs (resulting from egg depositions of flights of June beetles occurring in May and June of these two years) were very small and injury was practically eliminated.

In only 4 of the 15 renovations of 1934 were any white grubs found and these populations were very low, ranging from 4,000 to 8,000 grubs per acre. In the adjacent unrenovated grass, the grubs were present at the rate of 34,848 to 314,000 per acre except in two densely sodded pastures where no grubs were found in the renovated or unrenovated portions. Compared with untreated grass, the 15 renovations of 1934 reduced the grub populations by an average of 98%.

In the 15 areas renovated in 1935, only one was free of white grubs, the remainder containing populations ranging from 3,178 to 74,000 per acre, while in the unrenovated pastures from 47,916 to 333,000

grubs per acre were found. The average reduction in grub populations due to the renovations of 1935 was 91%.

Renovation was much more effective in lowering the populations of white grubs when it preceded the beetle flights of 1934 and 1935 than when it preceded that of 1935 only.

Dense growths of dry-weather legumes reduced grub populations effectively, whether these plants were in the seedling or later stages of growth.

It is obvious that the differences between the numbers of grubs found in the renovated and unrenovated portions of bluegrass pastures were very significant, statistically. Similarly, significant differences occurred between the pasture areas renovated in 1934 and 1935.

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THE AGRONOMY TEACHER[1]

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THERE has been a marked improvement in agronomic teaching during the past 20 years. There are few, if any, agricultural institutions in the United States that have not given some study to curricula and methods of presentation. The JOURNAL of the American Society of Agronomy has published a rather large number of papers on the subject, all of which make stimulating reading for any teacher of agronomy.

NATURAL TEACHING ABILITY

The old adage, "Teachers are born—not made," is more important than most of us are willing to admit. It is easy to take on an assistant, distribute his time over research and laboratory, and gradually advance him into the class room. He may be a brilliant scholar or he may be some one you like personally, but he may make a very poor teacher. Far too many university teachers have advanced by this route. A young man with natural teaching ability coupled with a reasonable amount of teacher training methods usually makes a good teacher.

Just what is meant by natural teaching ability? Is the prospective teacher deeply and enthusiastically interested in teaching? What is the young teacher's attitude toward youth? Does he think in terms of the other fellow? Is he absolutely unselfish? Does he prepare and deliver his seminar reports in an interesting and a logical manner? Is this young teacher efficient in organizing and presenting his material? Does he absorb knowledge willingly and then is he able to pass on this knowledge to someone else easily and just as willingly? Does he have a two-fold purpose when taking course work, namely, absorbing knowledge for subject matter training and at the same time thinking in terms of what part he might use and how he would teach this same material if he were called upon to do so? Is he dynamic, positive, pleasing, and able to hold the interest of others? What are his personal habits? Does he use good English? Does he have a code of morals that you would prescribe for your own son and daughter? What is his attitude toward religion? A fine religious attitude evidenced by living a good clean life is very desirable, but to talk about religion, especially, during class periods, is out of place and usually very undesirable.

The success of any enterprise depends almost entirely upon the personnel and upon the placing of this personnel in the right place so that the most can be made from the natural ability and training of each individual. The greatest possible care and study should be given

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to the selection of undergraduate and graduate assistants, because it is from this group that most of the agronomy teachers are finally chosen.

THE TRAINING

The training of the prospective agronomy teacher must be both broad and specific. It is desirable that he be farm raised and farm minded. There are two good reasons for this. First, he deals largely with farm boys and needs this farm experience to understand the attitudes of rural students. Second, he needs this practical farm information to understand farm problems as they are presented to him and to give him poise and confidence, so that in turn his students will have confidence in their instructor. Teachers of elementary agronomy classes should be permitted to spend a part of each summer in travel and study over the state so that they become thoroughly acquainted with soil and crop conditions.

While farm experience and practical farm knowledge are essential, the agronomy teacher must have the very best technical training. If he is teaching in the institution from which he received his bachelor's degree, his advanced training should be obtained in some other place. A Ph.D. degree in itself is not worth much, but the advanced technical knowledge and training obtained in securing this degree are very valuable. It is necessary for teachers to have enough technical subject matter training so that they know that they do not know very much. A teacher who says, "I do not actually have a degree, but I have the equivalent when you consider my long period of experience," had better take a year's leave, and register for courses in plant physiology, ecology, genetics, or chemistry and see what has happened during the past 15 years. He may be an exception to the rule, but the chances are he will receive the surprise of his life. If the crops teacher has mastered botanical science, his course is likely to bristle with applied taxonomy, plant physiology, and crop ecology. In other words, soils and crops courses should deal with the applied principles of chemistry, physics, and all the plant sciences and should not be just a statement of agronomic facts.

An agronomy teacher without this advanced training is almost sure to fall short in his instruction. This, without doubt, is one reason why Haskell charged the agronomy teacher with this frank statement: "Crop credits are generally recognized by students as being cheap credits." A teacher can not impart scientific principles to his classes if he is not properly trained in botany, bacteriology, chemistry, physics, and other fundamental sciences.

TEACHER AND STUDENT OUTSIDE THE CLASS ROOM

There is an old saying that "One is promoted more rapidly for what he does outside of his regular working hours than for what he does during them." Many times this is true with the teacher. When the class work is over and the formal guards are down, teacher and student can really get down on the common plane and talk over some of the student's problems that will make an outstanding student out of one that otherwise might have been only average. This personal

guidance requires of the teacher hours of careful individual student study and a great deal of patience. Much valuable time can be lost trying to make something great out of nothing. Probably 25% of university students should never be in college. Since they are present it is necessary to assist these lower quartile students, but too much time should not be given to them. Frequently a boy with good or even above average ability will be doing work of the lower quartile caliber. College aptitude tests or a personal interview will help to discover these boys.

The agronomy teacher should be looking for the outstanding student, the upper 10 or even 5 in a 100. This is the group that has the ability. If they also have the character and leadership qualities, then the very good can be made better and by turning out this type of student the agronomy profession will go a long way in blotting out some of the accusations of the past. Outstanding students of this type can not be given too much guidance if it is done wisely. The adviser should sit down with the student at the beginning of the sophomore year and map out a complete course work program. This should be subject to change, of course, but the mere fact that the student's program has been planned develops a purpose and starts him to thinking and planning for himself. A little guidance during the sophomore year on the student's participation in school activities is not out of order. A wise hand in helping him to separate the wheat from the chaff may aid the student in making a choice of life's values and help him to cut out some of the foolish student activities that will appear as mere trifles after he has matured. Most of this assistance must come outside of the classroom.

PUTTING THE TEACHING JOB FIRST

The teacher's first interest should be teaching and the researcher's first interest should be research. If the man whose chief interest is research tries to teach a large elementary class, either the research or the teaching, or both, are almost sure to suffer. The same thing would be true if the teacher attempts to carry a heavy research program.

Probably agronomy extension should not be left out of this discussion. As a matter of fact, if a teacher attempts much of an extension program he will be missing classes half of the time and this is never a good practice. These three divisions, however, should not be completely divorced. A teacher, who does nothing but teach, is likely to become narrow and rather academic. Is it not possible to build an organization within a department of agronomy where a teacher can make teaching his first interest and job, and yet, carry on in addition an important problem in research? This would give him opportunity to publish and also tell his results to farmers on various occasions.

The research man, on the other hand, should devote his major time to his experimental program but he should teach a class of advanced students at least one semester or quarter so that he does not feel entirely out of contact with the student body. He also should be given opportunity to contact farmers in the field so that he has a good picture of the problems confronting them. He can not, however,

be an extension agronomist. Neither can he answer all the inquiries nor should he be expected to answer the personal calls of farmers or the general service calls that come in over the telephone.

The extension agronomist should not be expected to teach regular classes or do much research. He should, however, be very closely associated with the other two divisions. Discussing a special subject before a class for the agronomy teacher is fine practice for him and his out-state contacts are of interest to students. He should extend the varietal testing and other practical farmer cooperative or demonstrational tests so that he can carry the work of the experiment station out to the public. The point is that there are three distinct divisions or lines of work in the average department of agronomy. One is just as important and essential as the other. There should be the closest cooperation, but the men in charge of each should certainly devote their major energy to their particular division.

THE AGRONOMY TEACHER AND INSTITUTIONAL RED TAPE

Every administrator appreciates a teacher who obeys the rules and laws as laid down by the institution and at all times uses good common sense. Employees think many times, that there is a serious conflict between institutional red tape and common sense. Usually, however, it has been the lack of the latter that has brought on more of the former. Obeying the rules does not destroy the freedom or self-expression of a teacher or any other employee. If the highway law says "Drive 45 miles per hour," then a university man with a university car should not drive more than 45. If the rules of the institution say, "No smoking in the halls," then the teacher or other employee should have enough self-respect to follow the rule. If the rules say nothing about the use of tobacco, alcohol, et cetera, then good common sense should be enough to control the behavior of the teacher The habits of the teacher are almost sure to be at least partially absorbed by the student.

Numerous minute details make up every great organization. Not many of these details can go wrong until the whole machine or organization begins to tumble. The human personality is a rather weak, fragile mechanism and it does not take very much to throw it off balance. The utmost care, therefore, should be taken in hiring, training, and directing a young teacher, because, as he does, so will his students.

The development of high ideals among our students in both subject matter and character is extremely important. Every department on almost any campus develops its own peculiar characteristics. The faculty members of some think in terms of the very practical. Judging of livestock and grain and practical feeding experiments and varietal tests of farm crops prevail instead of germ plasm studies and basic nutritional experiments. Some departments develop an attitude of loud speaking and bullying their students, while others stress an attitude of quietly developing curiosity, poise, and culture. The students in turn develop habits and attitudes accordingly and can almost be classified into their major departments without the use of registration slips or lists of advisers.

In agronomy we are interested in developing a type of student with high ideals and with an inquiring, analytical mind who will go out among his fellows teaching and thinking these ideals and in turn lifting the general level of fundamental sciences, which in turn will lift the general plane of scientific agriculture.

THE COURSE CONTENT

Mention has been made of the importance of the teacher's using a certain amount of fundamental science in the agronomy course content. Entirely too much worrying has been done in the past about duplication. Many say that the Smith-Hughes high school student should not take the elementary courses in agricultural colleges because of duplication and still others say that the high school courses in chemistry and physics duplicate those in the freshman year in college. If the college teacher has the proper technical training and knows how to handle his subject these elementary courses in high school do little more than arouse an interest on the part of the student.

The fact that a student has had elementary botany and a good course in taxonomy should not in any way worry the good crops teacher. This previous knowledge should have laid the foundation for some very excellent work on the taxonomy of the grasses and legumes. The average botanist considers the grasses and legumes two important botanical families among a large number of others. To the agronomist these represent the two most important botanical families and deserve much more detailed study. A college student should not only be able to identify the inflorescence and the seed of the grasses, but he should be able to classify them as to tribe, genus, and species and know the reason why they are so classified This study leads to the use of botanical keys and with the aid of a good grass bulletin with a key the student does not need to worry about identifying plants in the field.

Physiology and physical chemistry furnish many illustrations where the crops teacher can draw on these sciences to strengthen his course content and not infringe in any way on these fundamental subjects. It is not enough to know that the summer annual crops dry up after a frost. Why do they dry up? What is the best time to plant alfalfa on alkali land? Why? Why is early planting of winter wheat better than too late planting? Why plant the grasses and legumes just as early in the spring as freezing periods will permit? These whys all have a physiological answer. Anyone can look up the dates, rates, and depths of planting and the best variety to plant. These facts are all recorded in experiment station bulletins. Why ask the student to commit to memory something that you would not ask of any good farmer? Is it not too many of these elementary facts and not enough thinking and reasoning out the principles underlying the facts that have tended to cheapen our agronomy courses? If this above suggested type of agronomy teaching prevails, the botanist or zoologist has lost nothing, there has been little or no duplication, and the crops teacher has increased the value of his instruction many times over.

THE QUALITY TEACHER

It may not take a very smart man to be a university professor, but it does take a very wise university professor to be a good teacher. If we stop to think of the many times a teacher in any subject goes over the subject matter material in his course, it is not surprising that he is looked upon as a mental giant or some other uncanny piece of human intellectualism. Let the teacher remember that the blacksmith's arm becomes big and muscular because of the use of a hammer on the anvil. Any one who feels that a student should master in a 3-hour course the whole field of subject matter, should remember the first time he was exposed to the subject that now appears to be so easy. A student recently mentioned the fact that a certain teacher seemed to be able to tell in a class of 40 whether or not any one in the class failed to get his point. In other words this teacher was talking directly to his students, watching their faces, and if he saw bewilderment or doubt he backed up and tried another approach until he knew his class had a grasp of the problem at hand. This is a sign of quality teaching.

There seems to be a tendency for teachers who have traveled widely and who have grown older to mix too much of irrelevant experience into their course work outlines. Students often complain that a class is interesting, but the instructor talks about everything but the course content during the class period and then gives examinations on the subject matter. The students registered in the course for the purpose of gaining some knowledge on the subject at hand and did not care about mountain scenery or the students' conduct before and during a football game. Well thought out illustrations should be of great value and of interest, but an agronomy class is not the place for a travelog, especially when the teacher expects the student to cover a certain amount of subject matter material. The idea has been expressed more than once that if you want a good teacher, you had better choose one with the rank of an instructor, the assistant professor is very good, the associate good, the full professor fair, the head of a department poor, and a dean impossible.

SUMMARY

It has not been possible to cover all phases of the subject, but the following summarizes some of the most essential features which should characterize the agronomy teacher. He should:

1. Possess natural teaching ability.
2. Be able to use the best teacher training methods.
3. Be farm raised and rural minded.
4. Be most thoroughly trained in the biological, chemical, and physical sciences.
5. Be willing to confer with students outside of the class room.
6. Be able to select and guide the outstanding student.
7. Be able to develop personality and the finest character ideals in his students.
8. Be willing to stay in his own field and still maintain a broad-minded picture of the whole agronomy field.

9. Be able to cooperate with his colleagues and abide by institutional rules.

10. Be able to teach students to think and draw sound inferences with knowledge at hand.

11. Be able to distinguish between essential and nonessential knowledge and impart this power to his students.

12. Be able to impart to students the ability to apply acquired fundamental principles to ordinary agricultural problems.

CHANGING DENSITY OF WEED FLORA ON ARABLE LAND DURING THE COURSE OF THE "RABI" SEASON[1]

B. N. Singh, K. Das, and G. V. Chalam[2]

WITH the advance of experimental ecology, our knowledge of the phyto-climatic conditions bearing upon plant formations has also progressed. From the agri-ecological standpoint, plant-climate relationships have been studied by what might be termed the "macro" and "micro" methods of analysis. The macro method consists essentially of investigations into the regional distribution of the plant communities in relation to environment, while the micro methods have had to do with recording of the small changes that the plant reciprocates to the fluctuations of environmental variables. As such, a micro analysis of the specific changes in the density of the vegetation over a small area during the course of a season may give a correct idea as to the amount and nature of reciprocation of the plants to environment.

The greater possibility of homogeneity of the edaphic factors in a cultivated field has been taken advantage of to study the changing density of weed flora during the course of the "rabi" season[3]. But changes in density, comprising as it does the two opposite phenomena of the germination of some seedlings and the decay of others, cannot altogether be associated with the ecological factors since the physiologic complex of the weed species cannot be overlooked. It may not be possible, therefore, to arrive at any conclusive correlation between the incidence of winter weed species and changes in the climatic factors because of the marked periodicity of germination shown by most of the weed species.

Brenchley and Warington (1, 2)[4], during their extensive observations on the weed seed population of arable land, found that most of the species showed a definite periodicity of germination. They found further that under intensive methods of cultivation weed seeds in the soil appeared to have a period of natural dormancy as opposed to dormancy induced by unfavorable conditions. During this period of natural dormancy, the length of which varied with different species, the weed seeds did not start into growth even when placed under conditions favorable for germination.

Raunkiaer (5) has drawn attention to the important factors determining environment which ultimately expresses itself in the nature of the predominant flora. Of all the conditioning variables, he lays chief stress on temperature and precipitation. Recently, Warington (7), investigating the effect of constant and fluctuating temperatures on the germination of weed seeds in arable land, pointed out that the seasonal periodicity in germination evinced by several species is apparently due to temperature conditions though not

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[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication November 23, 1936.

[2]Kapurthala Professor of Agricultural Botany and Plant Physiology and research students, respectively.

[3]The winter crop season from October to March.

[4]Figures in parenthesis refer to "Literature Cited", p. 212.

exclusively so. Taking plant production as a measure of environment, Weaver (8) found that the water relations of the soil and air are the controlling factors of dry matter production while the other factors are merely contributory. Further he observed that the native and crop plants are found to integrate environmental conditions expressing themselves quantitatively in yield.

In the present paper, an attempt has been made to find by means of a statistical analysis of the data an interpretation of the changes in the density of the weed flora on arable land, and the influence of fluctuations in temperature and precipitation on the changes.

EXPERIMENTAL PROCEDURE

The observations on the changing density of weed species during the "rabi" season were made in a fallow plat of 80 square meters in area selected in the centre of a field which had been sown to wheat for a number of years. During the month of September, when all of the rainy season weeds were in full bloom, the plat was well plowed and harrowed. The plat was bordered with a thin wire, the wires were run lengthwise and crosswise at 1-meter intervals on the border wires, thus dividing the plat into quadrats of 1 square meter each. In a previous communication (6) the suitability of such a unit to quantitative studies of weed flora was demonstrated.

The total number of plants of all kinds and of the three species *Cyprus rotandus*, *Chenopodium album*, and *Euphorbia hirta* was counted separately at fortnightly intervals, the observations being recorded at the beginning of each half of every month. These three species were selected because they contributed the major portion of the vegetation and also because of the ease with which they could be identified in the seedling stage. A field note book was maintained with a page set apart for each quadrat upon which to record at fortnightly intervals the total number of plants and also the number of the three individual species found. The entire record of the field note book has been summarised in Table 1.

Records of temperature and precipitation were also taken, and fortnightly averages of the mean maximum, mean minimum, and mean temperature and precipitation are shown in Table 4. The hydrotherm values are also presented in Fig. 1.

DATA AND DISCUSSION

The observed frequencies of weeds when plotted against time gives a non-linear regression. As such the nature of the distribution of the changes in the numerican frequencies of the weed species may be well summarized by fitting in a parabolic curve. A parabola of the second degree following the equation $Y = a + bx + cx^2$, where Y and x are the two variants, namely, the expected number of plants and the time, respectively, while a, b, and c are the constants, has been tried for fit. The values of the constants have been calculated from the following equation since the values of y, x, n, $\Sigma(x^2)$, $\Sigma(xy)$, $\Sigma(x^2y)$, and $\Sigma(x^4)$ are known

$$\Sigma(y) = na + c\,\Sigma(x^2)$$
$$\Sigma(xy) = b\,\Sigma(x^2)$$
$$\Sigma(x^2y) = a\,\Sigma(x^2) + c\,\Sigma(x^4).$$

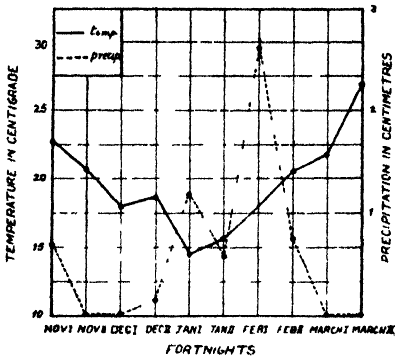

FIG. 1. - Temperature and precipitation during the period of study

The values of Y for each value of x have been calculated for the total density and for the three individual species and are shown in Table 1. The goodness of fit of such a curve is tested by calculating the mean squares of regression and deviation and testing it by Fisher's (3) "Z" by referring it to the simplified table of Mahalanobis (4). The results of the analysis of variance are given in Table 2. Furthermore, it is of interest to calculate the rate of change of Y along with the values of x by dfferentiating the equation $R = \frac{dy}{dx} = b + 2cx$, where R denotes the rate of change and b and c the calculated constants. The calculated rates of change during the successive fortnights for the total species and the three individual species are presented in Table 3. Since both b and c are constants, Y varies as 2x. The expected value of x when R = O, i.e., the period of maximum value of Y, has also been calculated from the formula $x = -\frac{b}{2c}$. Finding this value of x, the maximum values of Y have also been elucidated. The values of x and Y thus calculated have been put in Table 3 along with the values of R.

TABLE 1 — *Fortnightly changes in the numerical strength of three weed species, both observed and expected values*

Period	Total species		*C. rotandus*		*C. album*		*E. hirta*	
	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
Nov. I	1,376	2,254	613	1,054	446	1,155	93	150
Nov. II	4,224	4,038	1,256	1,561	2,331	1,797	314	429
Dec. I	6,467	5,442	1,729	1,953	2,874	2,306	847	636
Dec. II	7,216	6,466	2,448	2,228	2,836	2,682	925	801
Jan I	6,971	7,110	2,317	2,387	2,831	2,926	894	896
Jan. II	6,968	7,375	2,478	2,429	2,765	3,038	856	926
Feb. I	6,594	7,260	2,284	2,356	2,711	3,017	794	899
Feb. II	6,195	6,775	2,241	2,166	2,687	2,872	746	816
Mar. I	6,083	5,891	2,145	1,860	2,623	2,578	667	656
Mar. II	5,142	4,636	1,921	1,438	2,419	2,116	518	478

Testing the goodness of fit of the observed values of the numerical frequency by the "Z" test, it is found that $P<.01$ for total density of *C. rotandus* and *E. hirta*, while in the *C. album* $P<.05$ (Table 2). It may be concluded, therefore, that, in general, there is a close agreement between the observed and expected values of y. Figs. 2 to 5 show that the trend of the change in the density of the weed species during the period under observation has therefore been to increase

TABLE 2.—*Analysis of variance of the expected and observed values given in Table 1*

Due to	Degrees of freedom	Total species			*Cyprus rotandus*			*Chenopodium album*			*Euphorbia hirta*		
		Sum of square	Mean square	$x = \frac{s_1^2}{s_2^2}$	Sum of square	Mean square	$x = \frac{s_1^2}{s_2^2}$	Sum of square	Mean square	$x = \frac{s_1^2}{s_2^2}$	Sum of square	Mean square	$x = \frac{s_1^2}{s_2^2}$
Regression	2	23825906	11912953 (s_1^2)	23.3**	1930350	965175 (s_1^2)	10.6**	3389518	1694759 (s_1^2)	8.36*	570197	285098 (s_1^2)	20.1**
Deviation	7	3576431	510919 (s_2^2)	—	632717	90302 (s_2^2)	—	1414698	202099 (s_2^2)	—	98921	14131 (s_2^2)	—

*Significant at 5% level
**Significant at 1% level.

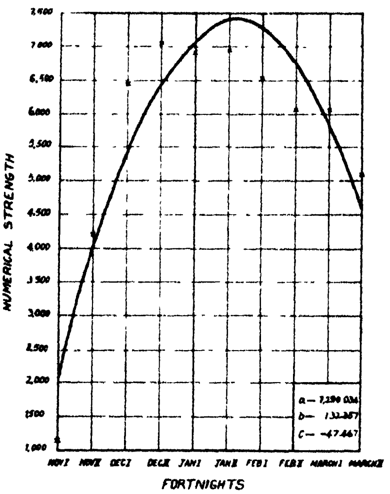

FIG. 2.—Total number of individuals in the successive fortnights.

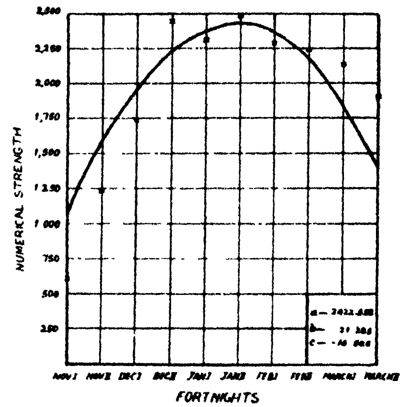

FIG. 3.—Number of individuals of *Cyprus rotandus* in the successive fortnights.

in numbers slowly, reaching a maximum by the middle of the period and decreasing towards the end but only to a certain level. Each of the individual species and the total vegetation possess this peculiarity in common and rise to the maximum practically during the same period. After attaining the maximum density, the individuals, due to the complicated action of competition and a host of other causal factors, begin to show a gradual decline, reaching a level by the end of March—the end of the season under observation—when all the plants are more or less in the senescent stage.

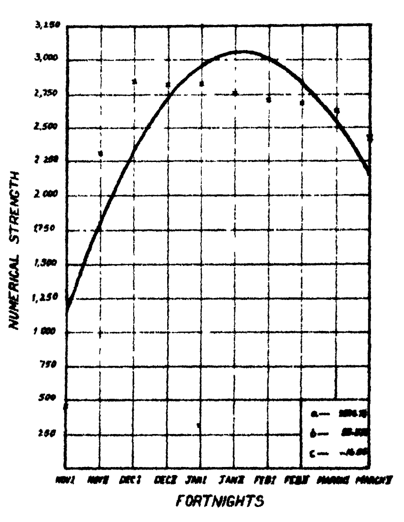

FIG. 4.—Number of individuals of *Chenopodium album* in the successive fortnights.

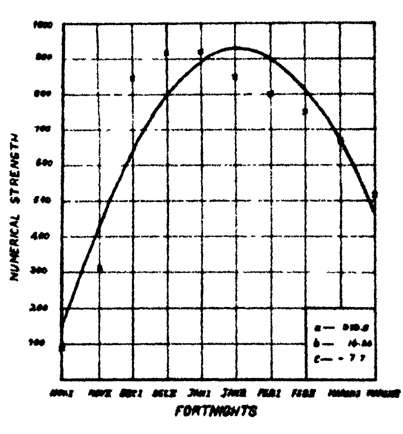

FIG. 5.—Number of individuals of *Euphorbia hirta* in the successive fortnights.

While the number of individuals increase from fortnight to fortnight, the rate of change (Table 3) shows a gradual fall and is characteristically present both in the total vegetation and in the individual species. The increase in number continues up to the middle of the season when a maximum density is reached. Under normal conditions of expectation, this maximum density in all the cases should be in the third week of January, except in the case of *C rotandus* where the maximum is roughly a week earlier (Table 3). Soon after the maximum density is reached, the number of weeds begin to fall. The rate of fall in numerical strength increases gradually in successive fortnights (Table 3) until in March the final minimum number of weeds for the period under observation is recorded.

TABLE 3.—*Rate of change of the density and the expected time and value of the maximum density*

Period	Total species	*C rotandus*	*C. album*	*E. hirta*
Nov. I	+987	+263	+354	+154
Nov. II	+797	+225	+288	+124
Dec. I.	+607	+167	+221	+ 93
Dec. II	+417	+108	+159	+ 62
Jan. I .	+227	+ 50	+ 89	+ 31
Jan. II. .	+ 37	- 8	+ 23	+ 0.84
Feb. I	152	66	− 44	− 30
Feb II .	-342	- 124	-110	- 61
Mar. I .	-532	- 182	176	− 90
Mar. II	722	220	242	-121
Expected time of maximum density	Middle of third week of Jan	End of second week of Jan	Middle of third week of Jan	Beginning of third week of Jan.
Value of maximum density	7382	2430	7382	928

In analyzing the relationship between the density and the two climatic variables, temperature and precipitation, the data (Table 4) have been analysed statistically. The simple correlation between the density and the average temperature and between density and precipitation have been calculated and the correlation coefficients found from the formula $r = \frac{P}{\sigma x \sigma y} \cdot \frac{\Sigma(xy) - n\bar{x}\bar{y}}{\sqrt{\{\Sigma(x^2) - nx^2\}\{\Sigma(y^2) - n\bar{y}^2\}}}$.

In finding the simple correlation, the partial correlation between each of the factors and density, eliminating the influence of the other, has been calculated and the coefficients found according to the formula

$$r_{12 \cdot 3} = \frac{r_{12} - r_{13} \times r_{23}}{\sqrt{(1 - r^2_{13})(1 - r^2_{23})}}.$$

The fortnightly trend of the mean temperatures during the season shows a steady gradual fall from the initial reading, reaching the minimum in the first fortnight of January when the temperature is only 14.4° C as opposed to 22.7° C at the beginning of the experiment (November). The temperature begins to rise again steadily until towards the end (March, second fortnight) a temperature as high as

TABLE 4.—*Fortnightly averages of temperature and precipitation during the period under study.*

Period	Temperature, degrees centigrade			Precipitation in cms
	Mean maximum	Mean minimum	Mean	
Nov. I....	30.7°	14.7°	22.7°	0.36
Nov. II .	29.1°	12.6°	20.8°	...
Dec. I. .	26.1°	10.4°	18.0°	...
Dec. II ...	25.3°	11.7°	18.6°	0.12
Jan. I....	20.7°	8.1°	14.4°	1.24
Jan. II....	22.1°	8.1°	15.6°	0.59
Feb. I...	23.9°	12.4°	18.1°	2.64
Feb. II....	28.8°	12.2°	20.8°	0.77
Mar. I.....	30.9°	12.6°	21.8°	...
Mar. II ...	37.1°	17.1°	27.1°	...

27.1° C is recorded. The difference between the mean maximum and the mean minimum temperature varies in the different fortnights between 12° and 20° C, showing the two extremes in the middle and at the end of the season, respectively, although the changes are gradual.

The precipitation during the period was irregular, there being no rainfall in the second fortnight of November, the first fortnight of December, and both fortnights of March. On an average the precipitation was low, as is generally the case during the winter.

The simple correlation coefficient between temperature and precipitation was + 0.25, showing little relationship of precipitation to temperature.

In general, there appeared to be some relation between temperature and density of the weed species (Table 5). In the case of total vegetation there was a significant negative correlation between density and temperature, showing that as the temperature decreased the density of the weeds increased, but as soon as the temperature began

TABLE 5.—*Simple and partial correlation coefficients between weed density, temperature, and precipitation.*

	Total species		*Cyprus rotandus*		*Chenopodium album*		*Euphorbia hirta*	
	Simple r	Partial r	Simple r	Partial r	Simple r	Partial r	Simple r	Partial r
Correlation between density and mean temperature......	−.54	−.6379	−.23	−.291	−.44	−.4724	−.66	−.9973
Correlation between density and mean precipitation......	+.23	+.5788	+.17	+.242	+.17	+.322	+.56	+.9968

to rise there was a decline in the number of weeds. Total vegetation, consisting of 14 heterogeneous winter and perennial species and a variety of life forms, responded to fluctuations of temperature, being inversely affected by the gradual fall or rise of temperature. As soon as the temperature began to rise, the more unsuccessful individuals in the struggle for existence perished as shown by a decline in numerical frequency. The partial correlation between density of total vegetation and temperature after eliminating the influence of precipitation was found to be significant (Table 5), showing that the negative relation between temperature and density was characteristically maintained.

The three individual species also maintained the negative relation between density and temperature (Table 5). Among them, *E. hirta* showed the greatest susceptibility to changes in temperature, the simple correlation coefficient and the partial correlation coefficient eliminating the influence of precipitation being significantly very high. *C. album* did not show a high correlation with temperature, whereas in the case of *C. rotandus* the correlation can safely be said to be significantly low. The possible explanation of the disparity of behavior between this species and the others can be found in the life form and growth habit of this species. *C. rotandus*, being a stem-geophyte in growth habit, has the buds or shoot apices buried underground. This favors their protection against changes of temperature in consequence of which the trend of the change in the density of individuals of this species is not affected by the changing temperature. Also, unlike the other species, new shoots may appear during the whole period thus maintaining practically the same level of density throughout. *C. album*, though quite hardy, is a therophyte and therefore, perhaps, the response to the gradual fall and rise of temperature is less pronounced than with either *E. hirta* or the total vegetation.

The influence of precipitation, on the other hand, did not appear, in general, to be significant, though there is a tendency nevertheless towards an increased density along with an increase in precipitation (Table 5). *E. hirta*, however, is the single exception to show a highly significant positive correlation coefficient between density and this variable. The partial correlation coefficient between density and precipitation, eliminating the influence of temperature, is also highly significant. This species, therefore, shows that with an increase in the amount of precipitation the density of individuals is also increased. The apparent anomaly in the relation between density and precipitation may probably be explained by the scanty and unequal precipitation during the period. It is interesting to note, however, the high degree of response of *E. hirta*, which is found throughout the whole year, to the influence of both of these variables.

The changing density of the vegetation is linked up with various internal and external factors of which the temperature at any stage of the life history of the weed species seems to be a greater controlling factor than precipitation. Even though these two factors cannot provide the full explanation of the phenomenon, temperature must be regarded as an important factor in determining the changes in the density of the winter weed species. This is even more evident when Warington's hypothesis of the controling nature of fluctuating

temperature on the periodicity of germination of weed seeds is taken into consideration.

The above analysis shows that with the onset of the dry season there is a considerable fall in the density of the weed species.

SUMMARY AND CONCLUSIONS

The changing densities of the total weed population and of the three species *Cyprus rotandus*, *Chenopodium album*, and *Euphorbia hirta* were recorded in an experimental plowed fallow plat during the course of a "rabi" season (October to March). The data collected at the beginning of each fortnight of each month revealed on statistical analysis that the curve of the best fit for the changing density of weed flora is a parabola of the second order. The trend in the change has, therefore, been to increase the number gradually, reaching the maximum during the middle of the season and falling again towards the end to a certain level.

Attempting to correlate the changes in the density of the vegetation and the fluctuations in the hydrotherm values which were recorded simultaneously, it has been found that of the two ecologic environmental variables, temperature seemed to be of greater importance than precipitation in altering the density. Temperature had a significant negative correlation with density except in the case of *C. rotandus*, which, due to its geophytic habit, is little influenced by temperature relations of the environment. Precipitation, on the other hand, had very little significant influence in changing the density except in the case of *E. hirta* which alone reciprocated to the changes in precipitation.

The above analysis of the changing density of weed flora on arable land and its correlation with changes in temperature and precipitation may aid in developing control measures in relation to the varied and complicated forces of invasion pressure.

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THE USE OF PARTIAL LINEAR REGRESSION TO ANALYZE THE CURVILINEAR RELATIONSHIP BETWEEN THE YIELD OF VEGETABLE CROPS AND THE CONTENT OF NUTRIENTS IN THE LOWER MAIN STEMS[1]

E. M. EMMERT[2]

THE application of correlation methods to the analysis of the relationship between yield and fertilizer additions of a given element or between yield and the availability of a nutrient is complicated by the presence of other limiting factors, as the amount of the nutrient is increased, and by the fact that the relationship is curvilinear instead of linear Partial correlation methods enable one to take into account the effects of other factors, provided a record of these factors is kept This means much additional work, especially if several factors are known to exert influence, but even additional work will not solve the problem of the curvilinear relationship.

Some rather laborious mathematical methods have been devised for curvilinear correlation which give the statistics called the correlation index and the correlation ratio. The determination of the correlation index necessitates a knowledge of the equation of the curve previous to starting the correlation computation This index simply tells how well the data fit a certain curve which is thought to approximate the actual relationships of the population involved For instance, the nutrient-yield relationship resembles a simple logarithmic curve. If this curve could be used it would simplify matters greatly because the log value of the nutrient could be used with yield, curvilinearity would disappear, and the usual linear partial or multiple regression methods could be applied to the whole nutrient range. However, the ordinary log curve has one rate of flattening out and only one. Environment and other limiting nutrients influence very greatly the rate of flattening out or the degree to which the law of diminishing returns applies. Hence the log curve might apply under a certain set of conditions but would not apply at all under another set. If it is always applied to the set of conditions which are most likely to occur, it would be of value, but this is not likely. Of course by means of introducing a change of base or certain constants in the proper manner it might be possible to adjust the curve. Adjusting the curve for each set of conditions, however, would require an exceptionally well-skilled mathematician, would consume much time in collecting enough data to show how to adjust the curve so it would fit and in performing actual curve fitting calculations, and would complicate the biological interpretation very much.

The correlation ratio devised by Karl Pearson tells how well the

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data fit lines drawn through the means of the columns in a correlation table where the data are thrown into a frequency distribution. This ratio, however, calls for the use of a large number of cases and the methods of partial correlation call for relationships of curves with known equations so that it would be impossible to calculate a partial correlation ratio for the yield-nutrient relationship where a large number of cases cannot be obtained and where partial correlation must be used to eliminate the effect of other factors. Furthermore, the correlation ratio cannot be used to get a quantitative expression for the relationship between two variables since it cannot be used to calculate regression coefficients.

In order to simplify and reduce the calculations required, to eliminate the difficult task of deriving the equation of a curve which actually fits the data, to determine the meaning of a small number of cases, and to enable the ready use of partial correlation methods, three partial linear regression lines were used in the present case to indicate the curvilinear relationship between potato yield and soluble nitrogen in the stems of potato plants. Phosphate phosphorus was recorded and its effect eliminated by partial correlation methods. The method for determining soluble nitrogen and phosphate phosphorus has been previously described (1)[3].

PROCEDURE

The data in Table 1 are from 37 different plats of potatoes grown on the Experiment Station farm at Lexington, Ky. Each figure for nitrogen or phosphorus is the average of two or three tests made upon the lower main stems of the potato plants.

1. *Arrangement of the data into groups of the variable nutrient to be correlated with yield.*—The first step is to decide how many regression lines can profitably be calculated from the data available. This depends on the number of cases at hand and also somewhat on the nature of the data. It seems best to divide the data into groups in such a manner as to make the frequencies in all about the same. Table 1 shows the data for nutrients determined on June 21, 1935, arranged in three groups so that the frequencies are 11, 15, and 11, respectively. It is necessary to do this so as to get as large a number of cases as possible in each range and thus make the statistics calculated as significant as possible, but the data should be subdivided sufficiently to give as good an idea of the course of the curve as possible.

It is apparent that as the number of cases increases, the number in each range may be increased to strengthen significance. Also, the number of divisions may be increased in order to come closer to the true course of the curve. If an infinite number of cases were at hand, it is obvious that an infinite number of perfectly significant regression lines could be calculated and the actual curve would be determined, since the regression lines would be merely points on the true curve.

2. *Calculation of the necessary statistics.*—The means, sums, and sigmas necessary in calculating the correlation coefficients are presented in Table 1. These were calculated in the standard ways (3, 4).

3. *Use of the t test to see if the differences between the yield means of the ranges are significant.*— Before calculating the correlation coefficients and regression lines, it is well to see if the differences between the yield means of adjacent ranges

[3]Figures in parenthesis refer to "Literature Cited", p. 219.

TABLE 1.—*Nutrients as parts per million of fresh tissue determined June 21, 1935, and yield of potatoes in pounds per plat.*

	Range 1, N = 139-233			Range 2, N = 257-555			Range 3, N = 556-1625		
	N	Yield	P	N	Yield	P	N	Yield	P
	139	33	195	257	38	160	556	42	188
	143	43	146	264	48	146	626	45	125
	147	40	120	264	39	146	700	63	146
	154	49	178	264	40	160	750	52	178
	162	43	266	264	38	250	834	46	188
	182	27	200	265	52	175	834	56	178
	186	55	260	286	49	114	908	65	105
	200	51	240	312	51	155	1,125	46	160
	208	45	170	330	46	260	1,200	58	122
	213	41	195	380	60	134	1,250	80	140
	233	57	146	436	57	130	1,625	70	150
	—	—	—	436	64	200	—	—	—
	—	—	—	470	55	134	—	—	—
	—	—	—	476	54	160	—	—	—
	—	—	—	555	37	155	—	—	—
Sum	1,967	484	2,116	5,259	728	2,499	10,408	623	1,680
N		11			15			11	
M	178.8	44.0	192.4	350.6	48.5	166.6	946.2	56.6	152.7
σ	30.5	8.5	45.2	96.4	8.4	40.2	306.0	11.5	37.1
r_{ny}		0.453			0.381			0.638	
r_{py}		0.112			-0.254			-0.448	
r_{np}		0.093			-0.095			-0.275	
$r_{ny.p}$		0.447			0.371			0.599	

are significant. This is done by calculating t values, using the simplified formula:

$$t = (M_1 - M_2) \sqrt{\frac{1}{N_1} + \frac{1}{N_2}} \div \sqrt{\frac{N_1\sigma_1 + N_2\sigma_2}{N_1 + N_2 - 2}},$$ in which M_1 and M_2 are the means of the groups, N_1 and N_2 the number in each group, and σ_1 and σ_2 the standard deviation.

The values for the data presented are, between means of groups 1 and 2, t = 1.296, p = 0.20, (when p = 0.05, t = 2.064). Between means of groups 2 and 3, t = 1.9364, p = about 0.06.

It is apparent from this that the difference between means of groups 1 and 2 is quite far from being significant, while the difference between means of groups 2 and 3 is just barely below significance when significance is taken as P = .05 (3). This indicates that the data may hardly be worth using to calculate regression lines and that the curve may not be very significant. The data are used, however, to illustrate the method, this being the best at hand to show the relationship between nitrogen and yield.

4. *Calculation of correlation coefficients.*—Simple and partial correlation coefficients are calculated in the usual ways (3, 4).

5. *Calculation of the partial regression lines.*—The formula for calculating the

partial regression lines was derived from the linear formula for a straight line, $y = y_M + r_{ny}\frac{\sigma_y}{\sigma_n}(n - n_M)$, in which y = the yield, n = p.p.m. of soluble nitrogen in the stem tissue of the plants, p = p.p.m. of phosphate phosphorus in the same, M = the mean of the group, N = number of cases, r = coefficient of correlation, and σ = standard deviation.

The partial features were inserted by substituting the partial coefficient, $r_{ny.p}$, for the simple coefficient, r_{yn}, and $\sigma_{y.p}$ and $\sigma_{n.p}$ for σ_y and σ_n. The formula obtained is $y = y_M + r_{yn.p}\frac{\sigma_{y.p}}{\sigma_{n.p}}(n - n_n)$.[4]

From this equation, the equation of the partial regression line for each range was calculated and the lines drawn in the graph (Fig. 1). These partial equations were found to be for:

Range 1. Y = 21.7 + .125n
Range 2. Y = 37.5 + .0315n
Range 3. Y = 36.8 + .021n

The values of the constants in these equations were multiplied by 4 in making the graph, to convert yields from pounds per plat to bushels per acre.

COMPARISON OF FIT OF THREE REGRESSION LINES TO FIT OF A STRAIGHT LINE

The total partial correlation coefficient, $r_{ny.p}$, was found to be 0.5669. This measures the fit of a straight line to the data. The next question was whether the three regression lines as shown in Fig. 1 fit the data better than a straight lines. A correlation index was calculated in the standard way by estimating the yields in each range, using the regression equation for each range, respectively. For instance, in group 1 the yield for 139 p.p.m. of N was estimated from regression line 1, thus y = 21.7 + .125 × 139 = 39.1 pounds per plat or 156.4 bushels per acre. The rest for that range were calculated thus, but when we come to the next group we have y = 37.5 + .0315 × 257 = 45.6 pounds per plat, etc. These estimated values were then subtracted from the actual values and ρ (correlation index) calculated in the standard manner. The calculation is as follows:

Sum of the squares of the differences = 2387.36

$Sy^2 = 65.06$

$$\text{Then } \rho_{ny.p} = \sqrt{1 - \frac{65.06}{113.54}} = 0.6534$$

It will be seen that the straight line accounts for 32.1% of the total variation while the three regression lines account for 42.7%,

[4]This formula is very satisfactory when one wants to show the estimated value of the dependent variable while removing the net effect of one independent variable without making any adjustment for it as is done in the regular multiple regression equation. In this case we are showing the dependent factor adjusted for the net regression with one independent factor, while not making any adjustment for the second independent factor whose effect has previously been taken into account in determining the partial coefficients. The proof of the equation from the regular multiple regression equation is the same as shown by Ezekiel in his book, "Methods of Correlation Analysis", page 195, except that he uses three independent variables and this equation uses only two.

or the regression lines account for 10.6% more variation than the straight line.

TESTS FOR REGULARITY AND CONSISTENCY IN DATA

The use of partial regression lines furnishes reliable tests for regularity and consistency in data. Fig. 1 shows at once that the data

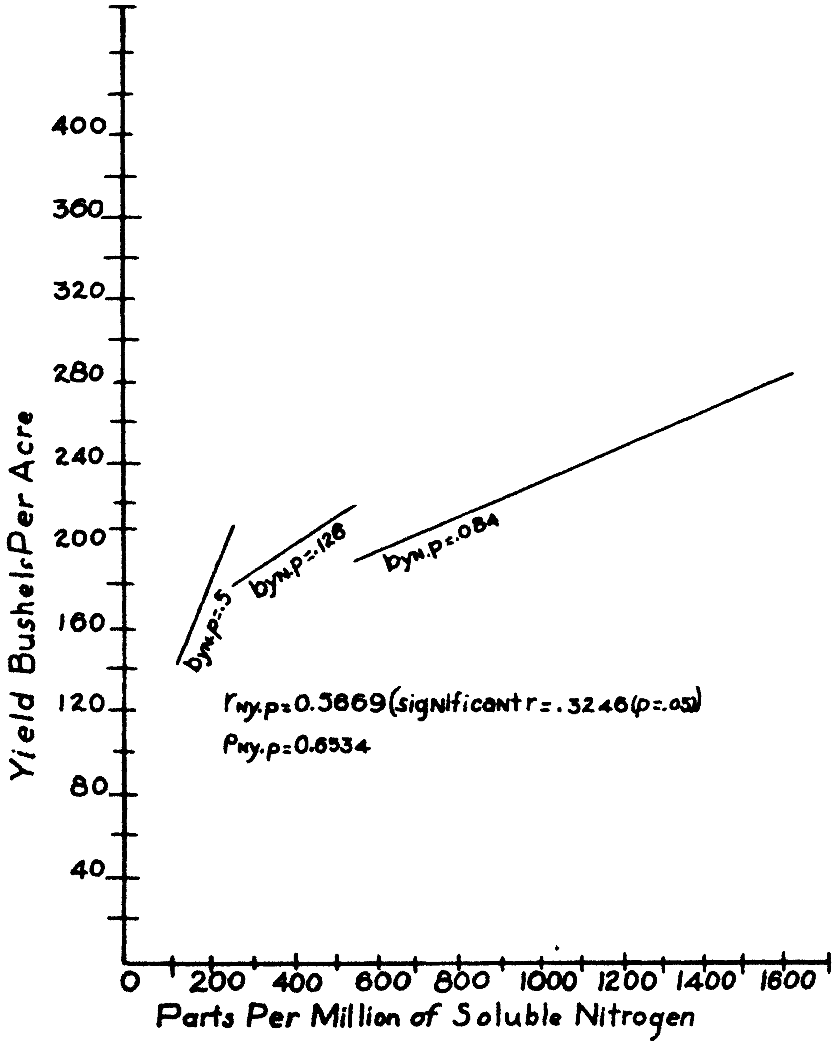

FIG. 1.—Partial regression lines for each range.

are not exactly regular and consistent in showing the progressive relationship between nitrogen and yield, even when the effect of phosphorus is eliminated. If the data were regular and consistent, the lines would tend to meet at the ends of the ranges and form a continuous line.

Another test for consistency is to change the range somewhat and see if the curve is still the same. When the four values of n = 264 in range 2 are shifted to range 1, we get the partial regression equations:

Range 1. $y = 39.7 + .020\,n$
Range 2. $y = 47.0 + .011\,n$
Range 3. $y = 36.8 + .021\,n$

This changes the nature of the curve considerably. If the data were consistent, the curve would not be changed materially by shifts in the ranges. Of course, even in fairly consistent data, if a shift of range is made so that one n is quite small great changes in the curve may be made. The test should be made by shifting the ranges in such a way that the frequencies in each range are still fairly close together and as large as possible.

INTERPRETATION OF RESULTS

Since the three regression lines fit the data considerably better than a straight line, as shown by the correlation indices (for straight line = .5669; for three regression lines = .6354), we will use the three regression lines in interpreting the data. These lines simply show that from 139 to 250 p.p.m. of nitrogen (phosphorus effects accounted for) the potato yield increases 0.50 bushel per acre for each p.p.m of nitrogen, from 250 to 556 p.p.m. of nitrogen it increases 0.126 bushel per acre, and from 556 to 1,625 p.p.m. it increases 0.084 bushel per acre. This flattening out of the curve is what would be expected since the relationship undoubtedly takes on some form of a Mitscherlich curve. Although phosphorus was eliminated, other factors undoubtedly caused considerable variations. Recording of fluctuations of other factors would aid in making the data more consistent. However, such factors as temperature and photo-period were practically constant in all plats. This means that these factors cannot be accounted for by regression lines since all values are the same for any one season. If records of many seasons were at hand, these factors might be accounted for, but all that can be done is to state that the above relations seem to hold for seasonal conditions existing in the spring of 1935 on the Kentucky experimental plats. The total rainfall during the crop season (May 25 to July 10, 1936) was 5.57 inches and was 2.56 inches for 10 days before June 21. The total average temperature was 74° and the average for the 10 days before June 21 was 73°.

Although results may vary some from this on a different soil type and under different seasonal conditions, these results indicate a rough general trend when a potato crop is receiving plenty of moisture. In fact, the determination of p.p.m. of nitrogen and phosphate phosphorus in the lower stems of the potato plants, if it were supplemented by determinations of potassium and soil moisture, would be more independent of soil type than direct correlation with actual fertilizer increments added to the soil because it would record the actual amounts of nutrients available to the plant. It is not intended in this paper to establish a yield curve for potatoes and nitrogen, since the data are too few and inconsistent. They are simply used to

illustrate the method for determining curvilinear relationships by the use of regression lines and methods for determining how consistent and regular the data are. If partial regression lines based on more cases and greater division of range were worked out, they should be more consistent and regular and form a basis to judge whether fertilizer additions would be profitable on a given soil.

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THE WHEAT MEAL FERMENTATION TIME TEST WITH SPECIAL REFERENCE TO ITS RELIABILITY AS A MEASURE OF QUALITY IN SOFT WINTER WHEATS[1]

G. H. CUTLER AND W. W. WORZELLA[2]

THE lack of a simple, quick, yet reliable test suitable for evaluating "quality" in small plant breeding samples has long handicapped the wheat breeder interested in developing new varieties of wheat of improved quality. In attempting to meet this problem, the wheat meal fermentation time test was developed by the writers in America (7, 8)[3] and by Pelshenke (23, 24) in Germany.

This quick test has attracted a great deal of attention among wheat breeders, cereal chemists, millers, and others, and is now being used quite extensively in evaluating "quality" in wheat. Most investigators who have used this test are in agreement that it is capable of rendering results that correlate satisfactorily with other measures for "quality". In a recent paper, however, Swanson and Parker (29) point out that the fermentation time test meets the demands for simplicity, but that the "question of its reliability is yet open for discussion". The present paper reports a statistical study of a limited body of data with a view of appraising the reliability of the wheat meal fermentation time test as a measure of "quality" in wheat in comparison with other popular methods such as the protein content and baking tests.

The writers fully appreciate that the term "quality", though relative, includes many factors Of these, however, it is pretty generally agreed that the most important is gluten strength, or baking strength as it is often referred to It is in this sense only that the term "quality" is used in this paper. In making comparisons between the fermentation time test and the protein content and baking tests, the writers also wish to point out that there is no desire to imply that the fermentation time test is an alternative to either or both of the other tests, rather do they emphasize the fact that the data employed in these studies are comparable and thus lend themselves to an analysis of this kind.

REVIEW OF LITERATURE

Many reports have been published on the wheat meal fermentation time test during the last 6 years. The following give the present status of the test as used by various investigators.

In testing a large number of varieties of wheat of known quality, Albizzatti (1), Borasio (4), Breakwell (5), Cutler and Worzella (7), Edel (10), Frankel (11),

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[3]Numbers in parenthesis refer to "Literature Cited", p. 225.

Griffiths and Cayzer (12), Hickinbotham (15, 16), Schnelle and Heiser (26), and Swanson and Parker (29) found that, in general, the results obtained with the wheat meal fermentation time test were in agreement with their known milling and baking behavior as determined by the trade.

Chapman and Farquhar (6), Cutler and Worzella (8), Griffiths, Norris, and Wenholz (13), Hauser (14), Hilgendorf (17, 18), Lieber (20), Meneret (21), Pelshenke (23, 24), Safta (25), Shibaev (27), Swanson (28), Wilson and Markley (30), Wilson, Markley, and Bailey (31), and Winter and Gustafson (32) obtained significant correlations between the results obtained with the wheat meal fermentation time test and those of other tests of quality, namely, the baking test, protein content, the Berliner and Koopman swelling method, the Barbender *farinograph*, Engledow's distensometer, Chopin's extensiometer, and Swanson's recording dough mixer, respectively.

Consistent "fermentation times" were obtained with wheats varying widely in gluten strength when grown in different seasons by Cutler and Worzella (8), by Hickinbotham (15), and by Worzella (33).

On the other hand, Mohs and Klemt (22) are not very favorable to the fermentation test and prefer the baking test; however, later Klemt (19) admits its usefulness in connection with other tests for evaluating quality Bayfield (2) reports unsatisfactory results with the recommended 10-gram doughball used by Cutler and Worzella

MATERIALS AND METHODS

The data reported in these studies were obtained from the regular tri-state variety standardization tests. The varieties used represent both soft and semi-hard winter wheats and were grown during the years of 1930 to 1934, inclusive.

After the varieties were threshed and run over a grader to remove chaff, dirt, etc., a representative sample was drawn. This was again sampled and part of it was used in protein content and baking tests while the balance was employed in making fermentation time tests.

The protein content and baking tests were carried out in the National Milling Company laboratories at Toledo, Ohio, under the supervision of Dr. E. G. Bayfield and V. Shiple, while the fermentation time tests were conducted by the authors in the laboratories of the Agronomy Department at Purdue University Agricultural Experiment Station. The reader will note that the tests from which these data were obtained were made independently, on as near identical samples as it is possible to produce, and at the same or nearly the same time each year. These facts are mentioned because in a comparative study of this character such procedure greatly enhances the value and significance of the resulting data.

The technic used in the wheat meal fermentation time test was as described by Cutler and Worzella (8). The protein content was determined by official approved methods, while the procedure used in making the baking tests was the basic A.A.C.C. formula with slight modifications from year to year as reported by Bayfield (3).

CRITERIA OF RELIABILITY

The criteria used as a basis of reliability in the studies consisted of (a) consistency of performance and (b) the ability to measure variation or spread in baking quality between soft wheat varieties. Some consideration was given, also, to a comparison of results obtained by each test to the known behavior of the different varieties when employed by the milling industry. This was based on conversation

with millers who have used many of the different types of wheat included in these studies. Furthermore, the findings of other investigators who have used the wheat meal fermentation time test in appraising the quality of wheat varieties or in correlating its results with other tests have been considered.

DATA AND DISCUSSION

CONSISTENCY OF PERFORMANCE IN THE FERMENTATION TIME TEST

Numerical data were obtained during each year for fermentation time, protein content (flour), and loaf volume for 12 varieties of wheat grown at each of three locations, *viz.*, Lafayette, North Vernon, and Bedford, Indiana, during the four harvest years of 1930 to 1933 inclusive. In subjecting these data to statistical analysis rankings were used based on the actual data. Accordingly, each variety was ranked for quality at each location, each year, in keeping with the data obtained by each test. The rankings received for each variety over the 4-year period (12 in number) for the three locations were then used as a basis for analysis. The varieties were arranged in the order of decreasing gluten quality as measured by the fermentation time test and the data are shown in Table 1.

TABLE 1.—*Relative ranking and variability of 12 soft and semi hard wheat varieties for quality as measured by fermentation time, protein content, and loaf volume when grown at Lafayette, North Vernon, and Bedford, Indiana, during the four harvest years of 1930 1933.*

Variety	No. of samples	Fermentation time			Protein content (flour)			Loaf volume		
		Range in rankings	Average ranking	σ	Range in rankings	Average ranking	σ	Range in rankings	Average ranking	σ
21-2-11...	12	1-5	1.67	1.15	1-4	1.42	0.90	1-11	3.83	3.13
Purkof ...	12	1-7	2.00	1.65	1-11	4.92	3.69	1-8	3.00	2.70
Michigan Amber.	12	3-9	4.42	2.27	1-12	6.50	3.21	3-11	7.92	2.74
Fultz....	12	3-7	4.83	1.27	6-10	7.58	1.45	1-9	6.42	2.35
Red Rock.	12	3-8	5.08	1.93	2-10	6.67	2.42	2-12	5.58	2.74
Berkeley Rock...	12	4-9	6.00	1.71	1-6	3.58	1.57	1-12	6.08	3.12
Fulhio....	12	2-10	7.08	2.81	2-6	3.83	1.80	2-12	6.25	3.16
Red Cross	12	2-10	7.08	2.15	2-10	5.58	2.54	3-11	6.25	3.25
Nabob....	12	4-11	8.16	2.52	8-12	10.42	1.24	3-12	8.50	3.29
Trumbull..	12	5-11	8.66	2.17	1-9	4.42	2.07	1-10	5.25	3.28
Gladden...	12	8-11	10.33	1.23	2-12	9.08	2.97	1-12	6.42	4.10
American Banner..	12	None	12.00	0.00	7-12	10.75	1.60	5-12	10.58	2.11
Average σ of individuals			1.88			2.27			3.04	
σ of the means			0.54			0.64			0.88	
Difference necessary for significance between two means, odds 19:1..........			1.27			1.50			2.05	

An examination of the data disclosed the fact that the ranking of the 12 varieties under observation is more consistent by the fermentation time test than by either of the other two tests. This is shown by the narrower range in rankings and a smaller standard deviation for each variety, as well as by the average standard deviation for all varieties, consisting of 1.88, 2.27, and 3.04 for fermentation time, protein content, and loaf volume, respectively.

A further study based on significant difference of means also reveals some interesting facts. The protein content test, for example, places Purkof, a wheat which the Indiana millers are pretty generally agreed produces flour too strong for pastry purposes, in the same group as such weak gluten soft wheats as Fulhio and Trumbull. Nabob, furthermore, is placed side by side with American Banner a white wheat possessing a very weak gluten.

The baking test, on the other hand, shows no significant difference between 21-2-11, a sister wheat of Purkof, and Trumbull; nor between Red Rock and Gladden, and yet these wheats are known to be widely different in baking quality. The fermentation time test shows significant differences between such varieties and places them more in accord with their known milling and baking behavior as experienced by the trade.

These data and analyses indicate rather impressively that the fermentation time test is capable of giving very consistent results in appraising the quality of varieties of soft and semi-hard wheats. In fact in these studies it gave even superior performance to either of the other tests. In reaching this conclusion the writers are not unmindful of the fact that the basic formula used in the baking test was slightly modified from year to year which may have had some influence upon the variability of the resulting baking data. Such of course does not apply to the protein test.

ABILITY TO MEASURE VARIATION OR SPREAD IN BAKING QUALITY BETWEEN SOFT WHEAT VARIETIES

It is a well-known fact that varieties within the soft wheat class differ in respect to baking quality. Since variation within a class is not as great as between classes, it is more difficult to appraise correctly the baking quality of such wheats. A test for quality must therefore be highly sensitive if these small differences are to be accurately appraised and interpreted. The wheat breeder is regularly confronted with just such a problem in attempting to select strains that are closely related. This characteristic of the fermentation time test was therefore studied comparatively with the protein content and baking tests. In doing so numerical data were employed for 12 varieties of soft winter wheat grown at Lafayette during each of 4 years, 1931 to 1934, inclusive. The varieties are typically soft and are commonly grown and quite extensively used in milling operations in the soft wheat region. The data, together with the rankings, are given in Table 2.

It will be noted that the coefficients of variability are about three times greater for the fermentation time test than for either

TABLE 2.—*Fermentation time, protein content, and loaf volume of 12 soft wheat varieties when grown at Lafayette, Indiana, during the harvest years of 1931–34, inclusive.*

Variety	No. of samples	Fermentation time, minutes				Protein content flour, %				Loaf volume, cc			
		1931	1932	1933	1934	1931	1932	1933	1934	1931	1932	1933	1934
		1*	1.5	1	1	4.5	6	5	1	6.5	2.5	5	4
Michigan Amber	4	93	59	75	62	7.5	7.8	9.1	11.5	420	560	580	530
		2	1.5	2	2	6	4.5	3	6	12	4	3	3
Red Rock	4	74	59	52	61	7.4	7.9	9.3	9.3	360	555	595	533
		5.5	3	3	3	4.5	7	6	4.5	8	6	3	1
Fultz	4	61	48	51	56	7.5	7.7	9.0	9.6	410	545	595	545
		7	4	4	4	7	4.5	1	2	1	7	10	9
Red Cross	4	55	46	46	54	7.1	7.9	9.5	9.8	480	540	537	493
		3	9.5	7	5.5	2.5	1	3	4.5	5	2.5	6	5.5
Fulhio	4	71	37	40	49	7.8	8.3	9.3	9.6	445	560	577	515
		4	5	10	7	1	3	7	8	2.5	5	7	10
Rudy	4	63	43	36	47	7.9	8.1	8.9	9.1	472	550	570	490
		5.5	7	8	8	2.5	2	3	7	6.5	1	8	7
Trumbull	4	61	39	39	43	7.8	8.2	9.3	9.2	420	570	557	510
		8	6	6	9	8	8	11	11	9.5	9	3	8
Nabob	4	53	41	41	42	6.9	7.6	8.3	8.5	380	525	595	505
		10	8	11	5.5	10.5	11	12	10	2.5	9	11	11
Purdue No. 1	4	52	38	32	49	6.5	6.9	8.1	8.8	472	525	535	485
		10	11	5	10	9	10	9	9	11	12	1	2
Gladden	4	52	34	45	40	6.7	7.0	8.8	9.0	365	495	607	535
		10	9.5	9	11	12	9	9	3	4	9	9	5.5
Poole	4	52	37	38	36	6.1	7.1	8.8	9.7	455	525	555	515
		12	12	12	12	10.5	12	9	12	9.5	11	12	12
American Banner	4	34	30	24	27	6.5	6.8	8.8	8.2	380	498	517	458
Mean		60.1	42.3	43.3	47.2	7.14	7.61	8.93	9.36	421.6	537.3	568.3	509.5
Standard deviation		14.6	9.1	12.7	10.3	.60	.53	.42	.83	43.4	24.2	27.8	25.0
Coefficient of variability		24.3	21.3	29.3	21.9	8.38	6.94	4.67	8.90	10.3	4.5	4.9	4.9

the protein content or baking data. Furthermore, the tendency of the varieties to rank the same way in the different seasons is also shown to be very consistent in the fermentation time test data.

In contrast the behavior of the protein content and baking tests is very different. Not only is the spread between varieties very narrow, as shown by the coefficients of variability, but the ranking is very inconsistent one year with another. The baking test performs very badly in this respect; for example, the Gladden variety ranks 11th and 12th the first 2 years and 1st and 2nd the next 2 years.

Under the conditions of these experiments, the results show that the wheat meal fermentation time test was a reliable guide in measuring the gluten quality of soft winter wheats. The results were not only in general agreement with what is known about the "strength" and "weakness" of the varieties studied, but much spread or variation was found among soft wheat varieties, and this was very consistent one year with another. Small differences were found in protein content and loaf volume in these same soft wheats with very inconsistent results especially for loaf volume.

SUMMARY

Statistical studies were made on comparable data derived from fermentation time test, protein content, and baking tests on (a) 12 soft and semi-hard varieties of wheat grown at three locations in Indiana in the four seasons of 1930 to 1933, inclusive, and on (b) 12 typical soft wheat varieties grown at Lafayette, Indiana, for 4 years, 1931 to 1934, inclusive.

The analysis of the data from these tests revealed that the fermentation time test accurately appraised the gluten quality of the wheats studied It gave consistent results one year with another at all locations. Much spread in quality was obtained among the soft wheat varieties.

Small differences were found in protein content and loaf volume in the soft wheats studied. Loaf volume data, especially, were inconsistent and erratic.

On the basis of these analyses, together with the favorable results reported by a large number of investigators, the fermentation time test may be regarded as a reliable guide in measuring the relative gluten quality of soft winter wheats.

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SOYBEANS IN THE NORTHEAST[1]

R. G. WIGGANS[2]

THE history of the initiation and long, slow growth of soybean production in the United States is well known. "Growing pains", however, were not apparent until very recently, during which time they have been tremendous and the production of the "Little Honorable Plant" has sprung from quiescent childhood into responsible maturity. This change is evidenced by the admission of soybeans to the Chicago Board of Trade. The first transaction was for 5,000 bushels at $1.20 in October, 1936.

During this initial period and the coming of age of this new crop as a real economic contribution, the corn belt generally has been found to be the best adapted and most promising area of production. This fact, however, has by no means eliminated interest in the crop in the northeastern part of the United States. The farmer, although conservative, is also inquisitive. His continuous and frequent queries would have forced the investigators of the region to establish certain facts upon which to reply to his questions, even though their natural desire for investigation of a somewhat questionable field had not led them into such studies. Every agronomic investigator in the northeast realizes in taking up such studies that he is in a sort of no-man's-land. He realizes that his province lies in a transitional area between the land of abundance on the one hand, and the land of barren wastes on the other as far as the production of soybeans is concerned. The climatic restrictions, the small units of tillable land, unsuitable machinery, the lack of varieties adapted to the particular purpose for which the beans are to be produced, and the cultural idiosyncrasies as well as the proper use of the crop after it is produced, all suggest that the northeastern area cannot be expected to compete on an even basis with the more favorably situated agricultural regions. This is particularly true in producing the crop for grain. A logical supposition even without experimental evidence would be that soybeans in the northeast offer the greatest promise as a forage crop.

The object of this paper is to give certain experimental results as evidence upon which to form an opinion in regard to the possibilities of soybeans in the northeast and in New York State in particular.

SOYBEANS AS FORAGE IN THE NORTHEAST

The high cost of protein as purchased by the dairyman in particular throughout the area under discussion has forced him (1) to increase his leguminous forage as much as possible, as evidenced by the increased use of alfalfa and clovers and in the interest in soybeans as another possibility, and (2) to increase his home-grown concentrates of all kinds and if possible of one high in protein.

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Soybeans may be used as forage for soiling, hay, or silage. The high cost of labor practically eliminates their use as a soiling crop. If, however, the crop is used for this purpose its production as hay indicates its possibilities as a leguminous supplement for soiling.

Various experiments have shown that soybeans properly grown for hay in the northeast will give yields comparable to those secured in the corn belt. High-producing varieties yield 2 to 3 tons of hay, approximately equal in value to the same amount of alfalfa or clover hay. It might seem, therefore, that the crop should have found an extensive use for this purpose. Such is not the case. The chief trouble lies in the problems of curing. In order to get the plant to a satisfactory stage of development for hay, a stage at which the seeds are one-half to two-thirds grown, it is necessary to utilize the entire growing season, thus placing the harvest and curing period very late in September when weather conditions make curing of hay very difficult. These conditions practically eliminate the use of soybeans for this purpose, except in emergency cases. If this crop is to be used for hay in this area it should be harvested and cured during August under more favorable conditions. To take advantage of the natural growth curve and the higher percentage of protein, the plant must have reached a stage where the seeds are one-half or more maximum size. Only extremely early varieties will attain this stage of development. If such varieties are available or can be found or produced and at the same time will give satisfactory yields, then there may be a place for soybeans as a legume hay in the northeast

In Table 1 are given data illustrative of the performance of early, medium, and late varieties for New York conditions. The 2 years' results, if the varieties given are accepted as representative of the groups to which they belong, show that an early variety has reached its maximum dry matter production on or before September 5, after which date there is a marked loss. The two early varieties as given in the table have actually dropped a small percentage of their leaves

TABLE 1.—*Early, medium, and late soybeans for hay yield in pounds of dry matter per acre.*

Date of harvest	Year	Variety			
		Cayuga (early)	92637 (early)	Black Eyebrow (medium)	Wilson (late)
Aug. 20	1935	4,467	—	—	—
	1936	3,086	—	—	—
	Av.	3,776	—	—	—
Sept. 5	1935	5,612	5,231	5,506	5,063
	1936	3,657	3,615	4,213	3,682
	Av.	4,634	4,423	4,859	4,372
Sept. 25	1935	4,169	—	5,475	6,038
	1936	3,480	—	4,202	5,226
	Av.	3,824	—	4,838	5,632

by this date and before September 25 have matured to the stage at which all leaves are down, pods are fully colored, and beans have desiccated to a considerable extent. The medium maturing variety is shown to have reached maximum dry matter production by September 5 but has lost nothing during the next 20 days. On the other hand, the late-maturing variety shows nearly 30% increase during the same period.

The table also shows that there is no essential difference between the yield of the early and the medium varieties on September 5, while the late variety lags behind to a marked degree. The comparative stages of maturity favor the earlier over the later varieties as far as ideal development for hay is concerned.

These data indicate that an extremely early maturing adapted variety is just as good if not better for hay than later sorts under the conditions of the experiment, with the added advantage of harvest the last of August for best results. Incidentally, such a procedure permits of a fall-sown crop without any interference.

SOYBEANS FOR SILAGE

The highest producing soybean varieties grown alone will yield one-half to two-thirds as much dry matter at silage cutting time (September 15) as good silage corn varieties under New York conditions. Such performance does not warrant the farmer in producing soybeans for silage when the extra trouble and added difficulties are considered. If, however, he can increase the protein content of his silage and still harvest as much or more total dry matter from a unit area with little or no added effort and expense, he is interested. Investigations in the corn belt have shown conclusively that a combination of corn and soybeans causes a marked decrease in the grain yield not only in corn grain but in total grain. This has probably had its influence on the producers of corn for silage, delayed investigations, and determined recommendations to some extent. Since in silage, the entire plant is consumed and since it is total energy that is desired, the actual amount of grain in the silage plays a lesser rôle by far than might be concluded. Although somewhat controversial, this thesis can probably be successfully defended. Therefore, if the addition of soybeans to corn for silage causes a decrease in the grain but no loss, or an increase, in total digestible units and an increase in the percentage of protein, the practice is worthy of consideration.

A brief summary of experimental work covering a period of 11 years on combinations of corn and soybeans is given in Table 2. Three varieties of corn and six varieties of soybeans are taken from the larger number of varieties of both corn and soybeans used in the experiment. These results are representative and aid in simplifying the presentation.

All data in the table are expressed in gains or loss in dry matter compared to corn grown alone and are the average of 3 to 11 years with a minimum of five repetitions each year. The differences are highly significant as based on calculation of odds.

The effect of the competition on the yield of total corn is shown to be present in all cases and to vary from 12.5% to 16.9% according

TABLE 2.—*Effect on yield of dry matter per acre of a combination of corn and soybeans grown for silage purposes.*

Variety		No. of years in test	Variation in dry matter per acre of the combination from corn grown alone						Increase in dry matter per acre of combination over corn alone	
Corn	Soybeans		Decrease in total corn		Decrease in corn grain		Total soybeans			
			Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%
West Branch..	Wilson	6	917	12.5	601	15.3	1,406	19.4	489	6.9
Cornell No. 11	Wilson	6	941	14.0	489	19.6	1,629	25.0	689	10.9
Cornell No. 11	Wilson	11	964	16.9	453	26.2	1,700	31.0	736	14.2
West Branch..	Ill. 13–19	6	971	15.3	321	16.1	1,507	21.2	536	8.1
Cornell No. 11	Ill. 13–19	6	1,037	15.2	528	20.7	1,740	26.6	703	11.4
West Branch..	——*	6	858	12.5	330	15.2	1,358	19.9	500	7.6
Cornell No. 11	——*	6	826	13.0	420	18.5	1,581	25.2	752	12.5
Cornell (E)...	——*	3	967	15.8	516	19.2	1,851	30.8	883	15.0

*Average of results of six varieties of soybeans, viz., Haberlandt, Ill. 13–19, Midwest, Mansoy, Wilson, and Dunfield.

to the particular combination and to the series of years over which the particular test was run. The effect on the yield of grain in the corn expressed in percentage was invariably greater than the loss in total corn. Although not measured as such, the grain in the soybeans would not make up for the loss of grain in the corn, verifying the many results as obtained in the corn belt.

The production of dry matter of soybeans in the various combinations was found to be 1,358 to 1,851 pounds per acre, or 19.4% to 31.0% of the production of the same variety of corn grown alone. These effects combined show an actual gain in dry matter of 6.9% to 15.0%. The varieties of soybeans included in the data in Table 2 showed very little difference in their effect on the combinations while the variety of corn showed a marked effect. The larger and the later the variety of corn, the less the effect of soybeans on the corn, also on the total dry matter. Other data show extremely early or extremely late varieties of soybeans for the region to be unsuitable for use in a corn and soybean combination for silage.

The results as outlined above indicate sufficient gains to justify the practice in the region, yet many producers have made trial plantings and only a small percentage have continued the use of the combination. Mechanical difficulties and a lack of knowledge of the cultural needs of the plant explain the failure of the practice in most cases, but unsatisfactory results or insufficient gains have been reported along with the statements of others showing extremely satisfactory results, increases in production, and very noticeable gains in milk flow when a combination silage is used in preference to a straight corn silage.

The excessive rate of planting corn for silage as ordinarily practiced in New York State may be one cause of dissatisfaction with the

combination. Although 9 inches apart in rows 3 feet apart is the optimum rate of planting corn for silage in the region as determined by a long series of experiments, farmers persist in planting thicker. The effects of thick planting of corn in combinations with soybeans are shown in Table 3. Three varieties of soybeans were grown with each of two varieties of corn. The method of testing was the same as in the previous experiments. As shown in the preceding table, the introduction of a companion crop to corn always causes a reduction in the total corn and in the corn grain and in general the wider the spacing the greater the effect on total corn, but the less the effect on grain. The amount of soybeans in the combination always decreased with an increase in the rate of planting corn. The net results of these effects show an increase in total dry weight in all cases but the thickest planting, where Cornell No. 11 was used as the corn variety. Where West Branch was used an increase occurred only with the 4-inch and 6-inch spacings. The results on the total effect are not conclusive as contrasted to the previous experiments. Probable causes of the variation are the extreme and abnormal conditions of 1935 and the insufficient number of seasons. Further trials are necessary before this question is answered satisfactorily.

TABLE 3. *Effect on yield of dry matter of the rate of planting corn in combinations of corn and soybeans for silage purposes, 1935 to 1936, inclusive, average of three varieties of soybeans*

Corn spacing in the row, inches	Variations in dry matter per acre of combinations from corn alone planted 9 inches apart in the row, lbs.			
	Total corn	Corn grain	Soybeans	Net difference in total dry weight
	West Branch Sweepstakes			
12	1,627	−483	1,380	−248
9	−1,144	−438	1,244	100
6	−653	−537	980	327
4	−527	−946	720	194
3	−768	−1,194	647	−120
	Cornell No. 11 (Late)			
12	−1,800	−799	2,041	240
9	−1,399	−787	1,810	412
6	−1,168	−935	1,585	416
4	−774	−1,101	1,240	466
3	−1,254	−1,385	1,171	−83

SOYBEANS FOR GRAIN

The need for a home-grown, high-protein concentrate as a dairy feed in New York and other northeastern states has long been recognized. Soybeans as a grain producer have appealed to many farmers who are forced to spend most of their milk check for concentrates, particularly high protein concentrates. As a result this crop has been much experimented with by the dairy farmers during

the last 20 years. However, they were destined to be disappointed because of the absence of suitable varieties for this purpose. All the so-called early varieties of the standard commercial sorts which might be illustrated by Black Eyebrow and Manchu were too late for the northeastern area. Under New York conditions such varieties will mature two or three years out of five. No farmer can afford to take such chances. The problem of prime importance, therefore, is to obtain a suitable variety sufficiently early to mature satisfactorily every year. This problem would not seem too difficult in view of the location of Manchukuo, the premier soybean-producing area of the world. The area of greatest concentration of soybean production in that country overlaps in latitude the whole of agricultural New York and also extends considerably farther north. The effect of the length of day on maturity of soybeans, as shown by Garner and Allard as far back as 1920, would also lead one to conclude that there must be soybeans already in existence suitable for seed production in the area under consideration. It has been only in very recent years that any real attempt has been made to explore and exhaust the possibilities of Manchukuo as a source of soybean varieties suitable for grain production in the northern areas of the United States. These introductions have been made chiefly via the U. S. Dept. of Agriculture and distributed therefrom.

The performance of a few of these introductions is shown in Table 4, where the variations in yield per acre from the check both in row and plat tests are given. The actual yield of Cayuga, the variety used as check, is found at the bottom of the two divisions of the table. The row tests are the results of 10 replications of rows 3 feet apart and 50 feet long up to 1934, at which time the space between rows was reduced to 28 inches. The plat tests were repeated in the same way but were 6 rows wide and 50 feet long with the rows 1 foot apart. Equal numbers of germinable seed of each variety were planted and covered by hand.

The results show all lots more variable than the check which has been exceedingly uniform over the years, particularly in the drill plats. Some of the strains show an average yield greater than the check. Black Eyebrow and Manchu, as representatives of early commercial varieties of many years standing, are entirely too unreliable to justify their use. Even to secure the yields given, extra care had to be exercised as illustrated by the latest possible date of harvest, tying in extremely small bundles, and great care in curing. With all the possible precaution, the grain is seldom fully developed or of a satisfactory stage of maturity for seed purposes the following year.

Contrary to the results under different conditions and with larger, later growing varieties, the early varieties show greater yields when seeded in solid drill plats than in 3-foot rows. The results in 1934 and 1935 as stated above are from rows planted 28 inches apart. The difference here is less marked than in the earlier years with the wider spacing. These data are not exactly comparable, although secured from areas in close proximity one to the other.

These data seem sufficient to justify the conclusion that soybeans

TABLE 4.—*Soybeans for grain, 1929 to 1935, inclusive.*

Variety	Gain or loss in bushels per acre in comparison with Cayuga as check							
	1929	1930	1931	1932	1933	1934	1935	Average
				Row Test				
03654A	-10.19	1.73	11.71	2.96	15.75	9.51	5.19	5.24
54608-2	- 5.66	3.44	7.88	- 1.21	7.06	1.72	- 0.48	1.68
65344	- 1.09	2.07	4.10	- 1.09	3.00	0.40	3.09	1.50
63242-2	-10.21	3.53	8.22	- 1.02	5.30	2.44	- 2.39	0.84
65341	-11.98	1.73	6.96	.19	2.98	3.25	- 0.84	0.33
53933-B	-13.27	- 4.07	9.06	- 1.47	7.99	5.43	2.91	0.94
Burwell	——	——	——	——	——	- 2.16	- 7.18	- 4.67
Black Eyebrow	10.12	0.84	7.97	2.26	7.17	1.75	- 6.61	0.47
Minsoy	——	——	——	——	——	- 8.47	-16.22	-12.34
Cayuga, bu. per acre	18.17	20.58	26.81	25.05	26.48	30.36	33.26	25.82
				Plat Test				
03654A	——	——	——	0.87	6.93	10.12	- 1.05	4.22
91089	——	——	——	——	——	4.32	- 0.73	1.79
92583	——	——	——	——	——	2.47	0.84	1.65
65344	——	——	2.14	1.24	3.34	5.61	- 2.45	1.48
63242-2	——	——	——	1.38	3.54	3.50	- 0.17	1.37
54608-2	——	——	6.51	- 5.23	——	6.08	- 1.86	1.37
Black Eyebrow	——	——	——	——	- 8.07	2.97	-14.15	- 6.42
Manchu	——	——	——	——	-14.57	2.90	-11.30	- 7.66
Cayuga, bu. per acre	——	——	38.57	37.38	38.29	31.88	34.87	36.20

should be given consideration as a home-grown, high-protein concentrate under northeastern United States conditions.

In view of these and other results one strain has been introduced by the Cornell Agricultural Experiment Station and named "Cayuga". Its choice over some of the others in the table may be questioned, particularly since it is black in color, but various considerations, such as uniformity of performance, habit of growth, non-shattering, and earliness seemed to outweigh the disadvantages of color and the small differences in average yield.

The introduction of a new variety for grain production led to cultural questions, not the least of which is the matter of the proper rate and spacing of seed for the best results in the New York area. The plan followed for studying this question was to use the variety introduced grown in 4 row plots, 20 feet long, the central two rows of which were harvested. All plantings were repeated 10 times. The spacing between rows varied from 8 to 32 inches and the spacing within the rows from ½ to 6 inches. These spacings gave from 1 to 18 plants per square foot. All plantings were by hand and spacings were carefully made, particularly at the lower rates. All seed were counted

TABLE 5.—*Rate of planting test of early soybeans in the eastern United States, yield in bushels per acre, 1934–36 average.*

Plants per sq. ft.	Space between rows, inches				
	8	12	16	24	32
18	38.52 (1 in.)*	—	34.98 (½ in.)	—	—
12	38.60 (1½ in.)	36.03 (1 in.)	—	33.16 (½ in.)	—
9	38.84 (2 in.)	36.21 (1½ in.)	35.36 (1 in.)	—	31.47 (½ in.)
6	38.49 (3 in.)	35.44 (2 in.)	35.12 (1½ in.)	33.90 (1 in.)	30.24 (¾ in.)
4	36.24 (4½ in.)	35.41 (3 in.)	35.40 (2¼ in.)	32.91 (1½ in.)	30.62 (1⅛ in.)
3	37.24 (6 in.)	35.07 (4 in.)	34.22 (3 in.)	32.49 (2 in.)	29.57 (1½ in.)
2	—	31.57 (6 in.)	32.14 (4½ in.)	29.97 (3 in.)	28.08 (2¼ in.)
1½	—	—	30.36 (6 in.)	28.80 (4 in.)	26.53 (3 in.)
1	—	—	—	25.81 (6 in.)	23.94 (4½ in.)

*Figures in parenthesis show spacing in the row.

in preparation for planting the proper number. Allowance was made for any deficiency in germination and a 5% field loss. The seeds for each individual row were placed in separate envelopes.

Three years' results of a study of the problem are summarized in Table 5. Subject to further confirmation in subsequent years, the following general observations seem to be justified.

The narrower the space between rows, the higher the yield. There is only one exception to this rule in the 24 observations, each one of which represents 10 repetitions in each of 3 years.

Nine plants per square foot approaches very closely to the optimum rate with this variety and within the limits of this experiment, regardless of the width of row.

The nearer the approach to an even distribution of the plants in the area, the nearer the approach to the maximum yield for the variety.

The further observation of the remarkably small variation in yield between rates giving 3, 4, 6, 9, and 12 plants per square foot of area is interesting in verification of similar work with other crops, particularly small grains.

This rather general presentation leads to the conclusion that the place of the soybean plant in northeastern agriculture is not entirely clear, but that it shows sufficient promise to justify much more study and investigation within the area and a more thorough exploration of the northern soybean-producing areas of the world for more and better varieties suitable for the conditions under consideration.

THE EFFECT OF FREQUENCY OF CUTTING ON THE YIELD OF ALFALFA UNDER HAWAIIAN CONDITIONS[1]

C. P. WILSIE AND M. TAKAHASHI[2]

SCIENTIFIC studies on the growth behavior of forage crops in the tropics have been given but little attention. The need for more investigations in this important field has been emphasized by Paterson (4, 5, 6),[3] who has been concerned with these problems in Trinidad. In the extension of the cultivation of improved forage plants in tropical and sub-tropical regions, alfalfa has been one of those crops on trial. Due to high atmospheric humidity, excessive weed competition, and the expense of getting a clean stand established, alfalfa will probably never gain the importance in the tropics that it has in the temperate regions. It has been possible, however, under certain favorable sub-tropical and tropical conditions to obtain exceptionally high yields.

In Hawaii, especially in the drier sections, where the annual rainfall is not more than 30 to 40 inches, alfalfa has possibilities. It is often difficult to maintain a stand for a number of years, but yields may be excellent for the first 2 years.

At low elevations where the temperature range rarely exceeds 30° F throughout the year (extremes of 57° to 87° F), there is a continuous growing season. While growth is retarded during the winter months there is no dormant or rest period. Under these favorable conditions it has often been recommended that alfalfa be cut every 4 weeks, or that 12 or 13 cuttings be taken in one year.

It is well known among forage crop workers in the temperate zones that too frequent cutting of alfalfa will so reduce the root reserves that the stand will be materially injured during the cold dormant season, with a great reduction in yield the following year.

Graber and his associates (1) showed that under Wisconsin conditions, cutting twice a season gave higher yields over a period of several years than cutting three times a season. Kiesselbach and Anderson (3) in Nebraska have recommended cutting alfalfa when the crop was between one-tenth and one-half in bloom in order to get the most effective hay yields. Grandfield (2) has shown, in discussing 20 years of experimental work relative to the time and frequency of cutting alfalfa at the Kansas Experiment Station, that under temperate zone conditions the fall of the year is the critical period as far as organic root reserves and permanence of stand are concerned.

The present experiment was designed to show what effect frequent cutting would have on the yield of subsequent harvests and to determine at what stage the highest yields of palatable green forage could be obtained under conditions of a continuous growing season.

[1]Contribution from the Hawaii Agricultural Experiment Station, University of Hawaii, Honolulu, T. H. Received for publication December 5, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 241.

EXPERIMENTAL RESULTS

At the University Farm at Honolulu a field experiment was laid out in the random block arrangement, with 12 replications of three cutting treatments. The soil was a shallow, fairly well-drained, heavy bottom-land clay type, as uniform as could be obtained in that particular region. A crop of pigeon peas (*Cajanus indicus*) had previously been plowed under and two months later a second plowing had been given. The seedbed was prepared and the plats leveled and furrowed for irrigation. Seed of the Hairy Peruvian variety of alfalfa was inoculated by the pure culture method and planted in rows 2 feet apart at the rate of 20 pounds per acre on January 23, 1934.

When the seedlings were about 4 inches in height a heavy infestation of army worms ate off practically every plant nearly to the ground level. Poison baits and sprays were used and the plants made a remarkable recovery, resulting in a good stand on the entire area. The first uniform cutting on all plats was made 111 days after planting, on May 14, 1934. Following this initial cutting, three cutting treatments were started, *viz.*, (a) bud stage, (b) one-tenth to one-quarter bloom, and (c) full bloom stage. Samples were saved for the determination of moisture and yield calculated in tons per acre on the air-dry basis. After each cutting the soil was cultivated between the rows with a one-horse cultivator or hoe. The plats were irrigated regularly during dry seasons once in 10 to 14 days, and as needed at other times throughout the year. After 6 months a uniform fertilizer application of 100 pounds of ammonium sulfate and 300 pounds of superphosphate per acre was applied. Less than 2 years after the first cutting was taken, the experiment was discontinued. By that time the stand of alfalfa on most of the plats was so reduced, due to a heavy infestation of nut grass (*Cyperus rotundus*), that it was useless to continue the experiment. While it would have been most desirable to have continued it for a number of years, it was felt that the results obtained were worth while because all plats were cut at least 13 times. Under temperate zone conditions that number of cuttings would have been possible only over a period of at least 3 to 4 years.

At the time when the first uniform cutting on all plats was made, 111 days after planting, the plants were in full bloom. Yields obtained in this cutting are given in Table 1.

TABLE 1.—*Yields of air-dry alfalfa forage from uniform cutting over whole area with plants in full bloom.*

Treatment group	Subsequent treatment	Yield per acre, tons
1	Later cut in bud stage	0.71
2	Later cut in 1/10 to ¼ bloom stage	0.73
3	Later cut in full bloom stage	0.73

*All samples for moisture determination were dried to constant weight in a well-ventilated attic at a day temperature of 90°–95° F. The air-dry forage had a moisture content of about 9% throughout the experiment.

These yields show no significant difference due to the location of the 12 plats of each treatment group in the field. The yield should, of

course, be the same for the 12 replications of each treatment and distributed in the random block arrangement.

Twenty-four days after the uniform cutting treatment, the first harvest of the plats cut in the bud stage was made. Thirty-five days were required for the plats to reach the tenth to quarter bloom stage and 42 days for the plats to reach the full bloom stage. Subsequent cuttings were made whenever the proper stage was reached even though the time required varied considerably during the different seasons of the year. A total of 17 cuttings was taken from the plats cut in the bud stage, 14 cuttings in the tenth to quarter bloom stage, and 13 cuttings in the full-bloom stage, before the experiment was discontinued. The summary of plat yields obtained during the 12-month harvesting period from June 1934 to June 1935 under the three cutting treatments is given in Table 2.

TABLE 2.—*Summary of plat yields of air-dry alfalfa forage in tons per acre in 12 months.*

Block No.	Cutting treatments		
	Bud stage	Tenth to quarter bloom	Full bloom
I	7.7	11.7	14.0
II	5.9	10.4	11.4
III	6.6	7.9	9.6
IV	6.8	8.2	9.8
V	4.0	9.6	10.3
VI	4.6	7.3	9.2
VII	5.6	14.4	12.7
VIII	4.9	12.2	13.1
IX	4.1	7.4	12.7
X	6.8	8.9	11.4
XI	4.1	7.9	10.2
XII	6.4	7.9	8.8
Mean yields, tons	5.6	9.5	11.1

The plat lay-out with three cutting treatments and 12 replications in randomized blocks permitted statistical treatment by the "analysis of variance" method. Using the air-dry weights in tons per acre from Table 2, the analysis is shown in Table 3.

TABLE 3.—*Analysis of variance of forage yields given in Table 2.*

Variance due to	Sum of squares	Degrees of freedom	Mean square	F
Total	296	35	8.46	—
Treatment	192	2	96.00	48
Blocks	60	11	5.45	—
Error	44	22	2.00	—

The validity of the experiment as a whole may be determined by calculating the "F" value. The "F" value is equal to the treatment mean square divided by the error mean square, or 96 ÷ 2 = 48. The

required "F" (from Snedecor's Table 35) with 2 and 22 degrees of freedom, respectively, is 3.44 (7). The effect of cutting treatment is therefore definite.

For a comparison of treatment means, standard error and "t" values are determined. With an error mean square of 2.00, the standard error of a treatment mean of 12 plats is $\pm$ 0.41 and the standard error of the difference between two means is $\pm$ 0.58. The "t" value, or ratio of a difference to its standard error when P = .05 and N = 22, is 2.074 (Snedecor's Table 35).

A significant difference in treatment means using the 5% level is $.58 \times 2.074 = 1.2$ tons per acre. Referring to Table 2, it may be noted that the treatment mean for plats cut in the tenth to quarter bloom stage was 3.9 tons per acre greater than the mean for plats cut in the bud stage. Also, the treatment mean for plats cut in the full bloom stage was 1.6 tons per acre greater than the mean for plats cut in the tenth to quarter bloom stage. It may be concluded, therefore, that the forage yield of plats cut in the tenth to quarter bloom stage was significantly higher than the yield of those cut in the bud stage. Also, the yield of plats cut in the full bloom stage was higher than the yields obtained with either the tenth to quarter bloom or the bud stage cutting treatment.

The trend in yield over a period of numerous successive cuttings is shown graphically in Fig. 1.

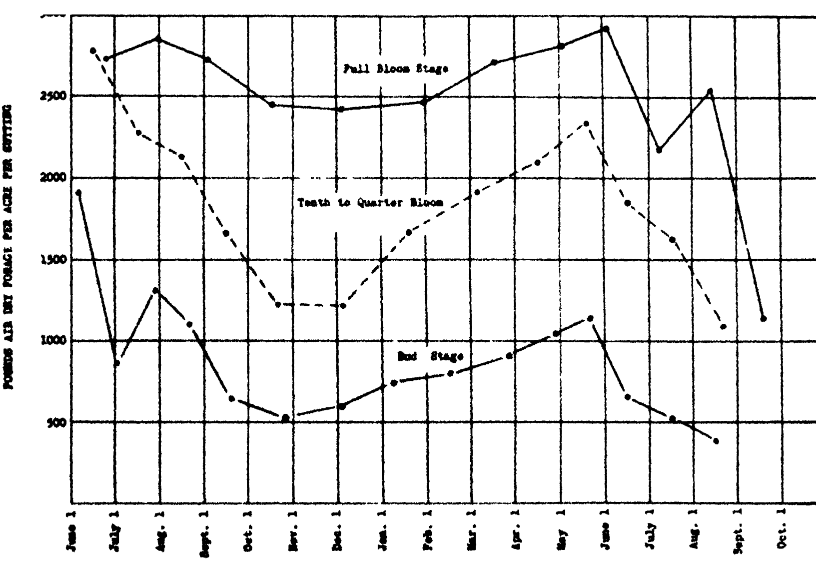

FIG. 1.—Yield trends of alfalfa with successive cuttings at different stages of maturity.

It is apparent that the most uniform successive yields were obtained from the full bloom cutting treatment. There was a sharp reduction in yield after the first cutting in both of the early cutting treatments, while the plats cut in full bloom maintained a fairly uniform level of production.

There was a noticeable seasonal trend in yield particularly in the plats cut at the early stages of maturity. A reduction in yield and an increase in the time required for maturity is noted from September to January. During the spring and early summer months from February to June an increase in yields and a shortening of the period required for maturity is observed. This was followed by a severe decline which resulted in the abandonment of the experiment in September, 1 year and 9 months after planting.

Yields of successive cuttings under the three cutting treatments are given in Tables 4, 5, and 6.

TABLE 4.—*Successive yields of air-dry alfalfa cut in bud stage.*

Date cut	Days of growth	Air-dry forage, lbs. per acre	Air-dry forage, lbs. per acre per day
June 7	24	1,912	79.7
July 2	25	858	34.3
July 27	25	1,318	52.7
Aug. 21	25	1,092	43.7
Sept. 18	28	658	23.5
Oct. 23	35	509	14.5
Dec. 4	42	601	14.3
Jan. 11	38	762	20.0
Feb. 18	38	791	20.8
Mar. 26	36	938	26.1
Apr. 27	32	1,061	33.1
May 21	24	1,186	49.4
June 15	25	683	27.3
July 15	30	506	16.9
Aug. 15	31	396	12.8

TABLE 5.—*Successive yields of air-dry alfalfa cut in tenth to quarter bloom stage.*

Date cut	Days of growth	Air-dry forage, lbs. per acre	Air-dry forage, lbs. per acre per day
June 18	35	2,796	79.9
July 18	30	2,270	75.7
Aug. 17	30	2,133	71.1
Sept. 17	31	1,657	53.5
Oct. 24	37	1,229	33.2
Dec. 4	41	1,229	30.0
Jan. 21	48	1,688	35.2
Mar. 6	44	1,905	43.3
Apr. 16	41	2,104	51.3
May 21	35	2,376	67.9
June 19	29	1,852	63.9
July 19	30	1,634	54.5
Aug. 22	34	1,112	32.7

It should be pointed out that the best stage at which to cut alfalfa depends to some extent on the use of the forage. For hay production cutting at the full bloom stage may result in too much stemminess, loss of leaves, and lower protein content, all of which tend to make the hay less valuable. When cut for use as a soiling crop only, to be

TABLE 6.—*Successive yields of air-dry alfalfa cut in full bloom stage.*

Date cut	Days of growth	Air-dry forage, lbs. per acre	Air-dry forage, lbs. per acre per day
June 25	42	2,740	65.2
July 30	35	2,862	81.8
Sept. 4	36	2,738	76.1
Oct. 16	42	2,445	58.2
Dec. 5	50	2,411	48.2
Jan. 29	54	2,454	45.4
Mar. 19	50	2,725	54.5
May 3	45	2,820	62.7
June 4	32	2,928	91.5
July 8	34	2,192	64.5
Aug. 12	35	2,536	72.5
Sept. 17	36	1,141	31.7

fed green, there is little loss except in a lower percentage of protein and slightly higher fiber content. All the forage was palatable and fed with practically no waste, so when used for this purpose, cutting in full bloom, which results in maximum yields, is probably justified.

SUMMARY

A field experiment concerned with the effect of frequency of cutting on the yield of alfalfa is reported. With 12 replications and three cutting treatments it was found that cutting in the tenth to quarter bloom stage gave higher yields than cutting in the bud stage, and that cutting in the full bloom stage gave higher yields than either of the other two cutting treatments. Under conditions such as prevail in Hawaii, with a year-round growing season, if the alfalfa is to be fed green as a soiling crop, cutting in the full bloom stage will probably give the most effective results, both from the standpoint of yield and persistence.

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VARIATION IN BUFFALO GRASS[1]

W. B. GERNERT[2]

IF there is a typical perennial "short grass" of the western prairies, it is buffalo grass (*Buchloe dactyloides*). It is also a mat grass of very dense nature, so compact that its sod served in many instances in pioneer days on the plains as building blocks for houses of the early settlers. Dimorphic in structure, it provides opportunity for intensified shortness in the pistillate plant of this monotypic genus (Fig. 1 A). Seedlings of *B. dactyloides* are monoecious, developing in turn both staminate and pistillate branches, which multiply their own kind vegetatively and to considerable extent in area. Solid blocks of either sex may be removed for transplanting, and in this way lawns have been set entirely with the very short female plants, which do not require mowing. Hitchcock (4)[3] uses *Buchloe* as the dioecious pattern in grasses.

The seed, or caryopsis-bearing spikelet, is thus borne so near or on the soil that it is impracticable to harvest it for seed with ordinary farm tools. On normal buffalo grass, the seed has been gathered by hand picking and by vacuum suction of the tough, coriaceous, seed-bearing spikes (Fig. 2 A). As high as 86% of the caryopses examined have been found ruined by fungi such as *Cercospora, Helminthosporium*, and *Ustilago*. In addition, many of the caryopses which appear healthy do not germinate readily and thus the actual viability of buffalo grass seed is usually low, so that until some way of producing viable seeds is found, as well as an economically successful method of harvesting it, vegetative propagation of this very interesting grass appears to be the most satisfactory method.

In the spring of 1935, some rank-growing female plants with elevated spikelets which appeared to be capable of seed harvesting with a common farm mowing machine were found on Arbuckle Mountain in southern Oklahoma (Fig. 3 A). Several rooted runners were propagated and in 16 months had produced a dense sward, during two record drouth years, with gratifying results. Two mowings with a hand sickle on eight plats, each one ten-thousandth acre in size, averaged air-dry hay at the following rates per acre:

First clip, Aug. 8, 1936	3.08 tons
Aftermath, Nov. 2, 1936	2.40 tons
Total (in one season)	5.48 tons

This plat (Fig. 3 B) is composed of all pistillate grass and a plat of staminate grass of this strain could be expected to produce greater returns by reason of its taller growth. The writer has found that pistillate spikelets shatter very decisively as soon as they are mature,

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[2]Associate Professor.

[3]Figures in parenthesis refer to "Literature Cited", p. 246.

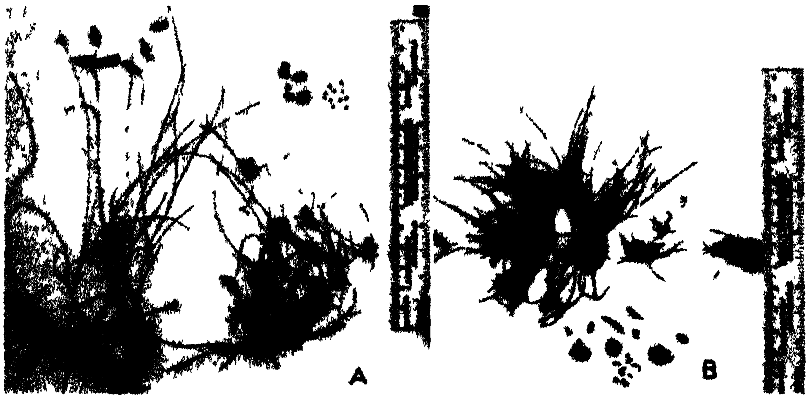

FIG. 1.—A, Staminate and pistillate plants also indupulvispathes and caryopses of typical buffalo grass (*Buchloe dactyloides*). B, "Nema" strain of buffalo grass only 3 inches tall, the horizontal strand shows the ground line. Male and female spikelets are shown also "nemacysts," non-viable caryopses galls.

hence the chief value of this strain then appears to be its forage production.

That this native grass of the plains region is desirable to maintain and propagate is evidenced by its own history during which it has supported *in situ* summer and winter great herds of cattle and, earlier, myriads of native animals from which it derives its name. According to analyses made by Daniel (1, 2), buffalo grass is not greatly different in nutritive value from some of the prominent grasses from which prairie hay is commonly made, as shown by the averaged data given in Table 1.

Bluestem and grama grasses are dominant in the native prairie hay of the plains uplands. The writer has risen very early in the morning and with a companion driven two wagons 10 miles into the

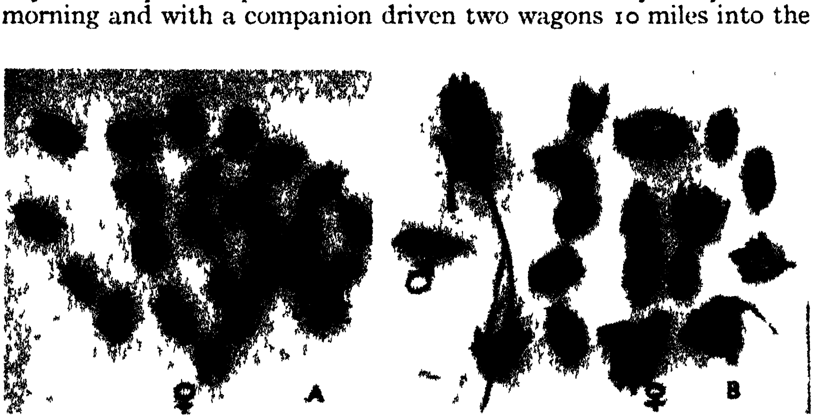

FIG. 2.—A, Normal and, B, nematode female spikes of buffalo grass. The central object (marked ♂) is a staminate spike of the "nema" strain. The male florets produced by this strain appear to be normal. X 2.

TABLE I.—*Averaged analyses of three prairie grasses.*

Grass	No. of samples	Mg, %	Ca, %	P, %	N, %	Protein equivalent
Little bluestem (*Andropogon scoparius*).....	73	0.1380	0.2615	0.0675	0.5790	3.62
Blue grama (*Bouteloa gracilis*)	16	0.1450	0.3135	0.1040	0.9325	5.83
Buffalo grass (*Buchloe dactyloides*).........	23	0.1480	0.3115	0.1170	0.9195	5.75

country, mowed, raked, loaded, and returned by nightfall with two great loads of cured bluestem and grama hay to be put in the mow before going to bed. This rapid cure would also be possible with buffalo grass hay, but it is generally considered too short to mow. A buffalo grass hay crop of more than 5 tons per acre per season seems well worth the undertaking (Fig. 3 B).

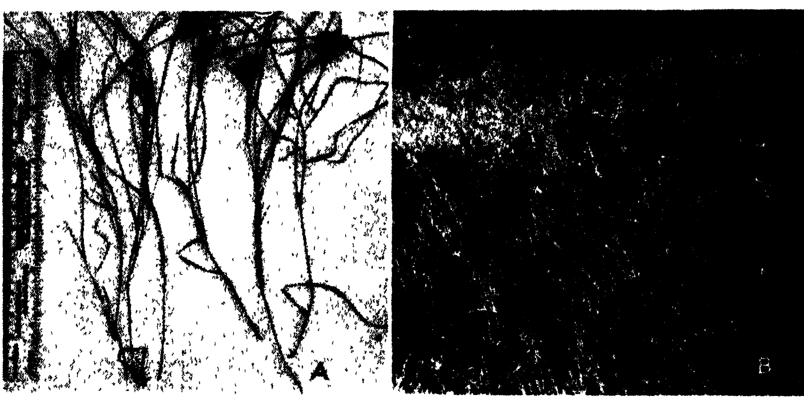

FIG. 3.—A, Arbuckle pistillate buffalo grass; B, producing greatly increased amounts of forage because of its much taller growth as compared to the usual type.

The writer has frequently observed that under permanent grazing the taller bluestem bunch grass is eliminated and buffalo grass replaces it on the dryer tight lands, while on sandy land and in moist ravines less desirable grasses and weeds may occupy the region. These observations are not in full accord with the report of Weaver and Fitzpatrick (6, page 188), that, "Although buffalo grass is often abundant in overgrazed pastures throughout the drier area, this species requires more water than the short grama grasses and is found sparingly in draws." On the tight, dry lands of western Oklahoma, buffalo grass is considered the most drouth-resisting grass of the upland prairie. It never becomes a weed, and with shallow surface growth and no underground rhizomes, it is easily subdued by plowing and cultivating.

Another very interesting variation in buffalo grass, so striking in its structure that it has been mistaken for another grass under expert

inspection, seems worthy of bringing to the attention of grass students and appears to be due entirely to the action of nematodes (Fig 1 B).

This strain was found by Mr. Gordon L. Powers while stationed at Stillwater, Oklahoma, and was kindly offered to the writer in the fall of 1936. Its growth is very short, somewhat thickened, and dwarfed, as is the case in wheat and other crops affected by nematodes.

This type, which we title "Nema" strain for lack of a more suitable name, produces pistillate spikes on prostrate surface runners with no elevated stems whatever. The glumes of the staminate spike appear normal, while the glumes of the pistillate spike, as shown in Fig 2 B, are elongated, thin, and chaffy, resembling somewhat the glumes of a brome grass instead of the tough, leathery, globular structure described by Hitchcock (4), but for which he did not suggest a name.

Piper (5) suggested the term "*Caryocyst*" from the Greek words for seed and box, for a descriptive name of the corneous glume-case typical of the single millet seed, which is quite dissimilar, however, from the encasement of the pistillate, several-flowered spikelet of buffalo grass. It does not seem consistent to call the growth either "bur" or "cyst," which latter term is generally in use for thin, hyaline bladders and fever vesicules. Hitchcock (4) uses the terms spike and head for the cluster or group of spikelets.

Since no properly descriptive word with few letters is at hand, the word *indupulvispathe* is suggested from the words indurate, meaning hard; pulvinus, meaning swelling; and spathe, a sheathing bract. The outer part of the *Buchloe* indupulvispathe has been identified by Hitchcock (4) as the second glume of the pistillate spikelet, developing at an oblique angle to the axis of the outer chaffy glumes of the normal spikelet.

The caryopsis region of the nematode spikelet is as curiously organized as the outer part, in that when the indupulvispathe becomes a series of broadened, elongated, and thinned chaffy parts, an enlarged gall is found invariably instead of a caryopsis or seed (Fig. 4 B).

FIG. 4.—A, Normal caryopes of buffalo grass (X 2). B, Galls filled with hibernating nematodes (microscopic worms). These galls or nemacysts will not germinate but will provide new colonies of worms (X 2). C, Second stage nematode larvae (X 140) obtained by crushing a gall or nemacyst in water and filtering moderately.

In the absence of appropriate terminology, the glume case in this instance will be called "*nemaspathe*" and the enlarged caryopsis sack a "*nemacyst*". When a female spikelet accidentally develops an uninfected inflorescence, it becomes invariably a normal indupulvispathe with normal caryopses inside (Fig. 4 A). An attempt will be made to germinate such seeds in the hope of learning what the nature and appearance of the resulting plants will be, if any.

The nematodes affecting this buffalo grass have been studied by Miss Gertrude Tennyson of the Plant Pathology Division of the Oklahoma Experiment Station, and she reports that the nematode is probably *Anguillulina agrostis* Steinbuch (3), as the measurements of the second stage larvae (Fig. 4 C), 0.82 mm long and 0.014 mm wide, correspond more nearly to those of *agrostis* (0.67 to 0.79 mm long by 0.014 to 0.015 mm wide) described by Goodey (3), as does the description of the pathological effects on its host inflorescence.

This report is made at this time with the purpose of pointing out some of the possibilities in selecting variable strains of native buffalo grass and what may be encountered in such work. Other variable strains are in the process of isolation and propagation. In the case of the Arbuckle strain which produced such outstanding yields, one-half or even one-fourth of the yields reported in this paper might be well worth working for under larger area conditions.

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EMASCULATION OF WHEAT BY CHILLING[1]

Coit A. Suneson[2]

FROST induced sterility has been widely recognized. Its occurrence in wheat has even been recorded in a prairie state.[3] Differential flower part resistance to frost has not been recognized, however, except in one case[4] wherein certain fruit flower stigmas were more susceptible than mature pollen. Some evidence that stamens might, under certain conditions, be the most susceptible of the vital flower parts was afforded in western Nebraska, coincident with the Kansas observations mentioned above. Publication soon thereafter of the preliminary report on the hot water emasculation method[5] prompted the work herein reported.

METHODS

A total of about 100 plants were used in these experiments, including winter, spring, and durum varieties of wheat. These were grown individually in 5-inch clay pots in the greenhouse. During two of the three years in which the experiment was active, supplemental light giving a June 1 day length equivalent at heading time was provided, making it possible for winter wheats sown in late October to head in February. Chilling was effected through use of the facilities in the Plant Pathology Department greenhouses, or by naturally occurring outdoor temperatures between 27° and 36°F. Treatments varied from 15 to 24 hours in length, after which the plants were always returned to their normal greenhouse environment for subsequent observation. The fact that a considerable number of variables, such as stage of development, variety, and length and intensity of exposure, were interacting in these experiments makes for difficulties in the presentation of data. It has seemed best, therefore, to present the results from only a few typical individual plants and to supplement this in the text with general inferences drawn from the complete record. In following these, it is important to recognize that different tillers on a plant react differently as regards type and degree of sterility.

RESULTS

Two general types of sterility were recognized in these experiments. One of these involved direct and similarly effective injury to all floral structures by temperatures of 27° to 30°F, manifested only in those

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[2]Assistant Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, recently transferred to University Farm, Davis, Calif.

[3]TIMMONS, F. L., and CLAPP, A. L. Floret sterility in wheat caused by late spring freeze. Jour. Amer. Soc. Agron., 24:584-585. 1932.

[4]SANDSTEN, E. P. Some conditions which influence the germination and fertility of pollen. Wis. Agr. Exp. Sta. Res. Bul. 4:162-165. 1909.

[5]STEPHENS, J. C., and QUINBY, J. R. Bulk emasculation of sorghum flowers. Jour. Amer. Soc. Agron., 25:233-234. 1933.

florets emerged from the leaf sheath but not yet fertilized. Such sterility was paralleled by similar injury to vegetative structures. This lack of plant hardiness at heading time should be noted for seedlings or young tillered plants otherwise comparable have endured 19°F exposures in other experiments by the writer without more damaging injury.

In the second type of sterility, absence of functional anthers was the pertinent characteristic. This type was observed in plants chilled throughout the full chilling range of 27° to 36°F; but occurred only in heads protected by the leaf sheath during exposure and which emerged from 1 to 5 weeks later. The severity of chilling and resultant plant reaction appeared to govern the time interval from chilling to emergence of self-sterile heads. Typical plant records showing various degrees of anther sterility in secondary tillers are shown in Table 1. These are of value chiefly in showing the range in the sterility produced.

TABLE 1.—*Typical expressions of anther sterility in secondary wheat tillers following chilling which had no marked effect upon the fertility of the primary tiller.*

Variety	Number days from		Self-fertile florets on successively heading tillers						
	Chilling to emergence of first head	First to last secondary head	1	2	3	4	5	6	7
Marquis	0	29	24	23	16	25	8	2	0
Ceres	0	16	24	21	17	30	18	13	—
Currell	1	32	26	14	0	0	0	0	—
Nittany	1	28	37	29	33	37	0	—	—
Minturki	2	19	27	21	3	0	6	—	—
Marquis	3	19	31	29	27	23	16	9	13
Currell	6	12	26	7	0	22	11	—	—
Kruse	7	12	21	13	4	6	—	—	—

A critical analysis of all of our data suggests varietal variation in tolerance to comparable chilling. Thus the variety Ceres, while not differing conspicuously from Marquis in vegetative injury following comparable chilling, was consistently more fertile and suffered less delay in completing emergence of all heads on the plant. Varieties also differed in their anatomical development following chilling. The Currell variety for instance developed as many as 17 florets per spikelet in some cases, while a selection from Turkey (Nebr. No. 1069) never exceeded the conventional 3 or 4 florets per spikelet.

In order to demonstrate that stigmas and other pistillate parts of the self-sterile heads produced by chilling were normal, foreign pollen was introduced between the glumes on one side of each of three sterile heads as shown in Table 2. The complete self-sterility of these heads was established as was their fertility if pollinated. The average seed set of 72% obtained compares favorably with that resulting from more standardized methods of hybridization. The hybridity of all of the seeds concerned was established in F_1.

TABLE 2.—*Use of foreign pollen on one side of self-sterile heads produced by chilling to demonstrate normalcy of pistillate organs.*

Variety	Plant data		Tiller featured			Fertility of head			
				Date		Control side		Foreign pollen side	
	Date chilled	Total number of tillers	Emergence number	Headed	Pollen applied	Number of florets	No. of kernels set	Number of florets	No. of kernels set
Marquis	Feb. 15	6	6	Mar. 12	Mar. 14	14	0	12	9
Currell.	Mar. 2	4	3	Mar. 11	Mar. 15	12	0	10	7
Kruse.	Mar. 3	6	5	Mar. 15	Mar. 19	14	0	10	4

In Table 1 it is apparent that the present technic has not always assured production of even one fully self-sterile spike per plant. This may not be necessary. The fact that self-fertile florets remained closed, whereas the glumes of self-sterile florets were held wide-open by the lodicules, permitted rapid and positive roguing of the selfed florets. This condition likewise permitted rapid application of the desired foreign pollen by dusting or blowing on to the exposed stigmas. On such a mass production schedule two or more spikes per plant were generally in condition for effective use. Even though in some cases application of foreign pollen was deferred as much as 5 days from the time of normal flowering, 35% of the florets so pollinated set seed. In this case, too, all seeds concerned were proved to be hybrids.

In pointing to low temperature as a vehicle for controlled emasculation, it seems pertinent also to call attention to the probability of similar reactions occurring in the field. In this case an exceptionally favorable setting for natural crossing would result.

BOOK REVIEWS

THE PRODUCTION OF FIELD CROPS: A TEXTBOOK OF AGRONOMY

By T. B. Hutcheson, T. K. Wolfe, and M. S. Kipps. New York: McGraw-Hill Book Co., Inc. Ed. 2. XVII + 445 pages, illus. 1936. $3.50.

THIS volume is a revised edition of one published by the first two authors in 1924 under the same title.

The first edition was published to meet the requirements of a standard course in field crops and as such is quite familiar to many teachers and other workers in agronomy. The second edition, according to the authors, not only brings the subject matter up to date, but the volume is also reduced somewhat in size so as to meet more closely the requirements of a one-semester subject. The reduction has come mainly in the number of tables presented.

A valuable feature not in the first edition has been added in the form of topic questions at the end of each chapter. Subject references have also been placed at the end of the chapters instead of at the end of the book. Aside from some rearrangement of chapters, the subjects covered are very similar to those of the first edition. As might be expected, considerable material is added on the more recent work in pasture and meadow management, also on root and fiber crops.

Those who have found the first edition valuable and helpful will welcome this revised edition. (R. C. C.)

THE EARTH GODDESS: A STUDY OF NATIVE FARMING ON THE WEST AFRICAN COAST

By G. Howard Jones. New York: Longmans, Green and Co. VII + 205 pages, illus. 1936. $5.

THE author of this book is the Director of the Mycological Section of the Ministry of Agriculture in Egypt. Previous to his present position he spent five years in Nigeria and Sierra Leone in similar agricultural work, and it was during this period that he made the observations which form the basis of this volume. It is an extremely interesting description and analysis of the native peasant farming under the primitive conditions of that part of Africa.

That the native agriculture bears an intimate relation to the religious beliefs of the peasant, as is also true of the American Indian, can be seen from such a chapter heading as "Ala, the Earth Goddess and the nature of agriculture". That it also bears a relation to modern agriculture is shown by other chapter headings such as "The Combination of Peasants: Agricultural Cooperation and its Potentialities", also "Schools and the Farmer".

The author's treatment is very sympathetic, both to native beliefs and methods. He shows how the native has developed an interesting blending of the scientific, the social, and the economic in agriculture

and gives consideration to how the native farming might be further developed and improved.

The book is well worth reading by the westerner both for the freshness and interest of the subject, and also for the author's views on cooperation and other matters. (R. C. C.)

AGRONOMIC AFFAIRS

SOIL SURVEY REPORTS WANTED

A GREATLY increased demand has arisen for soil survey reports and maps which in many cases are no longer available at the original source of supply. Dr. Henry G. Knight, Chief of the Bureau of Chemistry and Soils of the U. S. Dept. of Agriculture, urgently requests that anyone having copies of these reports and maps for which they have no further use send them to the Bureau for distribution to those who need them.

Upon request to Dr Knight, government franks will be supplied for the mailing of the reports.

NEWS ITEMS

MR. HARRY N. VINALL, Senior Agronomist in the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, died suddenly February 22 at his home in Washington, D. C., as the result of a heart attack. Mr. Vinall was long an active member of the Society, a frequent contributor to the JOURNAL, and served on various committees. For the past ten years he was mainly interested in pasture research and had administrative supervision over a number of field stations where pasture researches are in progress.

THE SUBCOMMITTEE ON SYMPTOMS of Malnutrition in Plants of the Committee on Fertilizers of the Society met at the Mayflower Hotel in Washington, D. C., on February 23, with Dr. Robert M. Salter, Chairman of the Committee, in the chair. In addition to J. E. McMurtrey, Chairman of the Subcommittee, other members of the Subcommittee present were O. C. Bryan, H. P. Cooper, O. W. Davidson, E. E. DeTurk, M. S. Hazen, G. N. Hofer, and J. J. Skinner. Ways and means were discussed of publishing in book form colored photographs and other illustrations showing symptoms of malnutrition in crops with chapters on cotton, corn and small grains, tobacco, potatoes, vegetable crops, deciduous and small fruits, citrus fruits, and legumes.

THE AMERICAN POTASH INSTITUTE has begun publication of THE POTASH JOURNAL designed to serve all groups interested in the business and economic aspects of fertilizer use and consumption with

special reference to potash. The JOURNAL will be published at the editorial offices of the Institute, Investment Building, Washington, D. C.

DR. SELMAN A. WAKSMAN has been elected a corresponding member of the French Academy of Science in recognition of his numerous contributions to soil microbiology.

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CARBON DIOXIDE PRODUCTION IN MANNITOL-TREATED SOILS AS A MEASURE OF CROP RESPONSE TO SOIL TREATMENTS[1]

W. B. ANDREWS[2]

IN 1935 the writer (2)[3] reported the results of a study of the relation between the response of soil micro-organisms and crop plants to nitrogen and phosphorus. The response of the soil micro-organisms to the fertilizers was measured by determining the effect of the fertilizers on the production of CO_2 by the soil after treating it with mannitol. It is generally accepted that CO_2 production is a measure of the activity of the organisms concerned, since CO_2 is an end product of respiration. The conclusion reached by the writer in the former paper was that, "The production of CO_2 in soils to which mannitol has been added under controlled laboratory conditions furnishes a basis for measuring the nitrogen and phosphorus requirements of soils tor cotton".

The literature reviewed in the former paper (2) shows that mannitol had been used in fertility measurements in which nitrogen fixation and mannitol disappearance were determined.

Cellulose has probably been used more than any other carbohydrate to supply energy for soil micro-organisms in the study of fertility plats. Waksman and Heukelekian (11), Starkey (10), Anderson (1), Carter (3), Holben (5), Shunk (9), and Nicklewiski (7) have reported data on the use of cellulose in microbiological studies of soils. The work of Holben indicates that its use is not entirely

[1]Contribution from the Department of Soils, Michigan State College, East Lansing, Mich. Taken from Part I of a thesis presented to the faculty of the Michigan State College in partial fulfillment of the requirements for the degree of doctor of philosophy, authorized for publication as Journal Article 274 n. s. of the Michigan Agricultural Experiment Station. Received for publication, November 9, 1936.

[2]Graduate Assistant in Soils; now Associate Agronomist at Mississippi State College and Experiment Station. The writer wishes to express his appreciation to Dr. L. M. Turk and Dr. C. E. Millar for valuable suggestions and criticisms tendered while the experiments were in progress, and to Dr. O. C. Bryan of the University of Florida, Dr. W. R. Paden of Clemson College, and Prof. M. F. Miller of the University of Missouri for supplying certain soil samples used in the investigations.

[3]Figures in parenthesis refer to "Literature Cited", p. 268.

satisfactory. He found that, "Plots receiving incomplete fertilizer treatments rank too high in CO_2 production to show any relation to crop yields. Several other high crop producing plots rank too far down the list in CO_2 evolution to credit this method as a reliable indication of soil productivity . . . When soil acidity is eliminated as a limiting factor . . . the CO_2 production and cellulose decomposing powers show very close agreement to crop yields". The investigators who have used cellulose to supply energy in soil fertility studies have used up to 30 days and several CO_2 determinations have been made.

The use of mannitol as brought out by the writer (2) usually reduces the time of the investigation to 24 hours and only one CO_2 determination is necessary.

The work reported by the writer showed the relation between the response of cotton and soil micro-organisms to similar fertilizer treatment, whereas in other fertility investigations where cellulose, etc., have been used, differences in fertility of soil from plats which had received different fertilizer treatments over a period of time were usually determined.

The results reported in the previous paper warranted further study to determine the applicability of the method for investigating differences in soil fertility plats and to determine if it might be used for ascertaining deficiencies of elements other than nitrogen and phosphorus. The effect of various soil treatments, such as air drying and additions of various proportions of $CaCO_3$ and $MgCO_3$, were also studied. The purpose of this paper is to report these investigations.

METHODS

Composite samples of the soil of the plow zone were taken and the fertilizers, 500 mgm of mannitol, and water were added to 100 grams of soil which were then mixed and put into 1,000-cc (usually) Erlenmeyer flasks which, in turn, were incubated for the specified time and the CO_2 determined by absorption in ascarite.

EXPERIMENTAL RESULTS

The following observations from previous experiments (2) and unpublished data were helpful in planning the present investigation. When the soils studied were treated with mannitol, the micro-organisms responded to applications of nitrogen and to lime and superphosphate only when nitrogen was added. The response to the above-mentioned nutrients was similar to that of cotton, but potash did not increase CO_2 production by the micro-organisms even when supplied to soils very deficient in this nutrient for cotton production. The greatest differences in CO_2 production were obtained during the first 24 hours. The largest quantities of CO_2 were obtained when the water content of the soil was 50% of the maximum water-holding capacity, whereas the largest quantities of CO_2, due to the addition of superphosphate, were obtained when the water content of the soil was 27% of the maximum water-holding capacity. The water content used in the remainder of the experiments was 33⅓% of the maximum water-holding capacity.

Superphosphate, when added to a soil deficient in phosphorus for cotton production, was used efficiently when P_2O_5 equalled in weight half of the added nitrogen (Table 1). When more was added, the increase in CO_2 production was very small. Even though increasing the temperature of incubation from 27° to 30° and 33° increased the CO_2 produced from 32 mgm to 42 mgm and 67 mgm, respectively, the increases due to nitrogen and to nitrogen plus superphosphate were practically the same at all three temperatures. Most of the later experiments were conducted at laboratory temperature.

TABLE 1 —*The effect of superphosphate on the production of CO_2 by a Ruston fine sandy loam with and without the addition of nitrogen.*

Treatment	Carbon dioxide production in 24 hours, mgm	
	Without nitrogen	With nitrogen
None........	24.0	110.2
12.5 mgm. 0-20-0 ...	24.5	198.9
25.0 mgm. 0-20-0	24.3	217.4
50.0 mgm. 0-20-0 ...	25.0	218.2
100.0 mgm. 0-20-0.....	24.6	207.5
200.0 mgm. 0-20-0	23.2	190.0

AIR DRYING

Waksman and Starkey (13) said that fungi are not destroyed by air drying soils. They (14) found that partial sterilization practically eliminated fungi. They (12) also reported data after McLennan (without reference) which show that desiccation did very little harm to spores of fungi, while only 4% as many colonies of fungi developed from mycelium after desiccation as before. Where field soils were desiccated, there were from 17 to 12.5% as many colonies of fungi as before desiccation. Several investigators have reported increases in the number of bacteria and CO_2 production due to air drying of soils. Increases in soluble nitrogen, phosphorus, and other minerals due to air drying of soils have been reported, while no increases have also been reported.

Since desiccating a soil kills the fungus mycelium present, the increases in numbers of bacteria may be due to the consumption of the mycelium by the bacteria. The decomposition of 250 pounds per acre of fungus mycelium containing 6.0% nitrogen would supply 15 pounds of nitrogen for the bacteria. The data in Table 2 show that the CO_2 production of two of the unfertilized soils was almost doubled on air drying and subsequent rewetting and that of three of the nitrogen-treated soils was considerably increased, but no increase was obtained in the case of 13 other soils while one showed a large decrease. The increase in CO_2 due to the addition of superphosphate to the second Olivier soil was nearly three times as great after air drying as before.

The effect of air drying the soil for a period of 8 months on the production of CO_2 is shown by the data in Table 3. In every case, the production of CO_2 by the unfertilized soil was increased by prolonged

TABLE 2.—*The effect of maintaining soils in an air-dry condition for a short time on CO_2 production during a 24-hour period after rewetting.*

Treatment*	Milligrams of CO_2 produced					
	Not dried	Air dried	Not dried	Air dried	Not dried	Air dried
	Houston Clay 1		Olivier Silt Loam 1		Norfolk Fine Sandy Loam	
None......	60.9	68.0	49.2	45.2	33.2	31.7
N........	70.5	108.9	109.6	101.0	67.8	65.2
NP........	163.5	177.9	114.3	113.7	124.4	124.8
	Houston Clay 2		Olivier Silt Loam 2		Lufkin Clay	
None........	45.4	49.6	52.3	70.8	22.9	27.0
N...........	63.2	54.3	42.1	52.7	18.9	23.6
NP..........	159.8	122.3	75.0	146.6	23.5	40.8
	Ruston Fine Sandy Loam 1		Cahaba Silt Loam		Orangeburg Fine Sandy Loam 1	
None......	28.2	60.0	32.4	42.2	31.7	40.4
N.........	149.9	183.4	73.8	70.8	164.0	173.6
NP..........	153.7	193.2	——	103.9	159.0	177.4
	Ruston Fine Sandy Loam 2		Granada Silt Loam		Orangeburg Fine Sandy Loam 2	
None......	32.7	63.2	32.1	31.9	40.9	62.3
N.........	79.8	102.6	40.2	39.0	191.0	207.7
NP.........	134.9	178.6	85.7	75.5	181.6	——
	Ruston Fine Sandy Loam 3		Fulton†		Lintonia Silt Loam	
None	22.5	35.9	73.7	52.3	68.6	65.1
N...........	81.1	88.3	181.2	170.1	184.3	177.8
NP........	132.1	147.6	187.2	164.0	211.4	202.8
	Montrose Clay Loam		Oktibbeha Clay		Pheba Loam	
None........	60.9	58.1	36.1	46.8	31.2	24.2
N...........	103.7	68.4	39.1	39.2	31.3	24.3
NP	127.7	91.2	66.4	——	56.6	41.6

*N = 30 mgm of nitrate of soda per 100 grams of soil; P = 25 mgm of 20% superphosphate per 100 grams of soil.
†Soil type not known.

air drying. On the other hand, the effect of air drying on the CO_2 production of soils treated with nitrogen and with nitrogen plus phosphorus was variable.

CALCIUM AND MAGNESIUM

The response of soil micro-organisms to additions of $CaCO_3$ and $MgCO_3$ was determined by the use of soil samples from the untreated plats of three experimental fields where limestone applications had greatly increased crop yields. The data, reported in Table 4, show that on the first Fox sandy loam where alfalfa had failed without lime, a 3-ton application of $CaCO_3$ increased the production of CO_2

TABLE 3.—*The effect of storing soils in an air-dry condition for 8 months on the CO_2 production at 30° C.*

Treatment*	Milligrams of carbon dioxide produced					
	Before storage	After storage	Before storage	After storage	Before storage	After storage
	Yohola Very Fine Sandy Loam		Olivier Silt Loam		Lintonia Silt Loam	
None.	50.8	78.1	47.1	51.6	44.8	74.3
N.	140.4	194.6	68.2	48.6	136.7	131.3
NP.	155.1	202.8	90.8	121.1	143.1	198.0
	Ruston Fine Sandy Loam 1		Ruston Fine Sandy Loam 2		Ruston Fine Sandy Loam 3	
None.	22.1	37.9	28.3	46.5	14.7	26.0
N	62.5	45.9	126.3	120.1	70.1	73.3
NP	91.9	107.9	133.1	164.3	101.5	133.4

*N = 30 mgm of $NaNO_3$ per 100 grams of soil; P = 25 mgm of 20% superphosphate per 100 grams of soil

TABLE 4.—*The response of soil micro-organisms to calcium and magnesium as measured by CO_2 production.**

Ratio of calcium to magnesium		Milligrams CO_2 produced by different soil types with different rates of application of lime which varied in proportion of calcium to magnesium			
		Fox sandy loam, 3 tons lime	Warsaw loam, 3 tons lime	Fox sandy loam	
$CaCO_3$	$MgCO_3$			3 tons lime	1 ton lime
0	0	9.8	74.7	32.6	—
100	0	59.6	59.2	65.8	64.6
75	25	64.9	92.9	66.2	—
50	50	69.7	98.2	71.4	59.8
25	75	80.4	—	—	—
0	100	79.4	—	—	—

*All soils used in the laboratory received nitrogen and phosphorus at the rate of 15 mgm of $NaNO_3$ and 12.5 mgm of 20% superphosphate per 100 grams of soil.

five fold. The replacement of $CaCO_3$ by equivalent increments of $MgCO_3$ up to 75% had a favorable effect on microbiological activity.

The production of CO_2 by micro-organisms in the Warsaw soil was reduced from 75 to 59 mgm by the addition of $CaCO_3$. Substituting 25% and 50% of the $CaCO_3$ with $MgCO_3$ increased the production of CO_2 to 93 and 98 mgm, respectively.

The production of CO_2 by the second Fox soil was doubled by the addition of $CaCO_3$; however, the substitution of a part of the $CaCO_3$ with $MgCO_3$ increased the production of CO_2 only very slightly with a 3-ton application and reduced it slightly with a 1-ton application. This soil came from a field where dolomitic limestone was more effective for alfalfa production than was a high calcium limestone.

The beneficial effect of the substitution of magnesium for a part of the calcium, in addition to the nutritive function of the magnesium,

may be due to the higher solubility of magnesium phosphates below pH 7 (8).

CALCIUM ARSENATE

Soil was obtained from a Norfolk sandy loam field which had received a toxic quantity of calcium arsenate through dusting cotton for boll weevils. Data in the forty-fourth annual report of the South Carolina Agricultural Experiment Station (1931) show that superphosphate decreased the yield of cowpeas on this soil presumably by precipitating soluble iron which would otherwise have reduced the solubility and toxicity of the arsenic. Addition of $FeSO_4$ to a large extent overcame the detrimental effect of the superphosphate, but $MnSO_4$ and lime were not thus effective. The data reported in Table 5 show that applications of superphosphate up to 800 pounds per acre increased the production of CO_2 in this soil, but increasing the application to 1,600 pounds and 3,200 pounds did not cause further increases in CO_2 production. These data indicate that the response of soil micro-organisms to superphosphate in the presence of arsenic is not the same as is the response of cowpeas.

TABLE 5.—*The effect of superphosphate on the production of CO_2 by an arsenic-sick Norfolk fine sandy loam.*

Treatment per acre*	CO_2 production in 24 hours, mgm
None	56.9
0-20-0, 100 pounds	90.1
0-20-0, 300 pounds	126.3
0-20-0, 400 pounds	130.9
0-20-0, 600 pounds	141.2
0-20-0, 800 pounds	143.1
0-20-0, 1,600 pounds	140.0
0-20-0, 3,200 pounds	134.4

*All cultures received an application of 600 pounds of $NaNO_3$ per acre.

Since $FeSO_4$ reduced the calcium arsenate toxicity to cowpeas in the field induced by superphosphate, studies were undertaken to

TABLE 6.—*The effect of Na_2SO_4, $MgSO_4$, $Al_2(SO_4)_3$, $FeSO_4$, $CuSO_4$, and $MnSO_4$ on the production of CO_2 by calcium arsenate-treated soil.*

Treatment per acre*	Mgms CO_2†
None	139.2
500 lbs. calcium arsenate	100.9
500 lbs. calcium arsenate + 400 lbs. sodium sulfate	91.1
500 lbs. calcium arsenate + 400 lbs. magnesium sulfate	92.8
500 lbs. calcium arsenate + 400 lbs. aluminum sulfate	64.8
500 lbs. calcium arsenate + 400 lbs. iron sulfate	92.0
500 lbs. calcium arsenate + 200 lbs. copper sulfate	61.6
500 lbs. calcium arsenate + 200 lbs. manganese sulfate	92.7

*All cultures received an application of 600 lbs. of $NaNO_3$ and 500 lbs. of 20% superphosphate.
†Amount produced in 24 hours.

find out whether this and other sulfates (sodium, magnesium, aluminum, copper, and manganese) would have a similar effect on soil micro-organisms. The data reported in Table 6 show that all of these salts when applied to arsenic-treated soils which received superphosphate and $NaNO_3$ in addition caused decreases in CO_2 production. In other words, they were not effective in alleviating the toxic effect of calcium arsenate to soil micro-organisms.

ZINC, MANGANESE, AND COPPER

Soils were obtained from the Florida Experiment Station which were known to be deficient in these elements for certain crops. The data reported in Table 7 show that none of these elements was effective in increasing the CO_2 production by the respective soils.

TABLE 7.—*The effect of $ZnSO_4$, $MnSO_4$, and $CuSO_4$ on the production of CO_2 by certain Florida soils known to be deficient in these elements for the production of field crops.*

Treatment per acre*	Mgms CO_2†
Norfolk Fine Sand	
None	155.5
$ZnSO_4$, 80 lbs	153.4
$ZnSO_4$, 200 lbs	149.3
Marl	
None	126.3
$MnSO_4$, 100 lbs	113.0
$MnSO_4$, 200 lbs	111.0
Leon Sand	
None	37.3
$CuSO_4$, 40 lbs	35.2
$CuSO_4$, 80 lbs	35.6

*All cultures received an application of 600 lbs. of $NaNO_3$ and 500 pounds of 20% superphosphate

†Amount produced in 24 hours.

EFFECT OF CERTAIN SOIL TREATMENTS ON CROP YIELDS AND THE PRODUCTION OF CO_2 BY SOIL MICRO-ORGANISMS

The following discussion deals with the relation between the yields of crops on fertility plats and in greenhouse cultures and the production of CO_2 by the micro-organisms in the soil of each respective plat or culture. The various soil treatments include fertilizers, lime, green manures, and crop rotations.

Fertility plats, Fox sandy loam soil.—Soil samples were taken from a series of soil fertility plats which were laid out on a Fox sandy loam soil in 1917. Lime, applied in 1917, has produced very large increases in yields of crops, but the plats were all in need of a second application of lime when the samples were taken in 1934.

The quantity of CO_2 produced by soil from the check plat as shown in Table 8 was very low and was only slightly affected by added fertilizers. CO_2 production during the first 24 hours is considered a

measure of the microbiological activity of the soil and is indicative, therefore, of the numbers of bacteria and the fertility of the soil. The CO_2 produced by the laboratory checks during the first 24 hours and the average grain and straw yields, excluding those for the 2 years following the plowing under of a legume, are plotted against the soil treatments in Fig. 1. The yields for the first 2 years after plowing under a legume were discarded because the unlimed plats did not produce legumes, and the turning under of the legume crops probably exaggerated the differences between the limed and unlimed plats. The soil samples were taken 7 years after plowing under a legume.

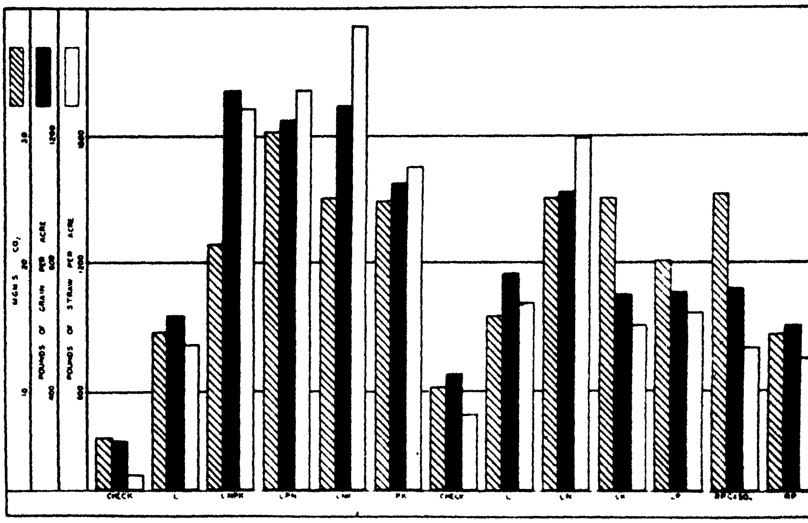

FIG. 1.—Relation of fertilizer and lime treatment in the field to crop yields and CO_2 production.

In general, the production of CO_2 follows the production of grain and straw closely, although the yields from the plats which received nitrogen were slightly higher than the production of CO_2 would indicate. This may have been due to the fact that the crops used up the added nitrogen or to the fact that nitrogen stimulated crop growth and induced a greater removal of the other elements. According to Winogradsky (15) and Ziemieka (16), it may also be accounted for through a reduction in the Azotobacter population of the soil as a result of the nitrogen treatment; however, other bacteria may have decreased in number also. The yields of the lime-potash and rock phosphate-calcium sulfate plats were lower than the CO_2 production would indicate.

Since the plats under consideration were so badly in need of lime when sampled, it is not logical to assume that the yields during the 17-year period are a true picture of their relative fertility levels at the present time, and therefore, it would be unwise to attempt a direct correlation. All that can be said is that the treatments have changed the biological activity of the soil and that the plats have at

TABLE 8.—*Production of CO_2 in mgm under different laboratory treatments by soil taken from fertilizer plats of a Fox sandy loam.**

Laboratory treatment	Field treatment					
	Check	L	LNPK	LNP	LNK	LPK
Check. .	6.3	14.0	22.8	30.5	25.2	24.8
N . . .	6.2	22.9	17.7	28.7	30.3	30.7
P. . . .	6.8	10.3	20.1	28.0	24.7	24.9
NP. .	6.6	23.9	18.0	30.5	36.8	33.9

Laboratory treatment	Field treatment						
	Check	L	LN	LK	LP	RP $CaSO_4$	RP
Check	11.4	16.6	25.1	25.0	20.3	25.7	13.7
N. .	9.5	27.2	36.2	34.0	29.1	34.1	40.3
P.	10.7	16.2	23.5	23.5	17.2	21.4	17.0
NP .	9.4	27.1	41.1	39.7	26.6	34.5	42.5

*L = lime, N = nitrogen, P = phosphorus, K = potash, R P = rock phosphate

the present time practically the same relative fertility as the treatments produced in the yield of the crops.

The correlation coefficient between CO_2 production and grain yield is .79 ± .107; that between CO_2 production and straw yield is .75 ± .120. The correlations are sufficiently high to indicate a close relation between the production of CO_2 by mannitol-treated soil and crop yields by these plats.

Carter (3) used soil from most of these plats for CO_2 production studies using cellulose as the source of energy. His results do not show the spread between the low and the high crop producing plats which is indicated by the crop yields. The method using mannitol, therefore, corresponds more closely to the crop yield method of determining soil fertility than the method using cellulose, as carried out by Carter. At least part of the objections which Holben (5) offered, to using CO_2 production from cellulose in soil fertility studies seem to apply to Carter's data.

Fertility Plats, Putnam silt loam.—In the summer of 1934, soil samples were collected from certain plats in the Sanborn, Mo., experimental field. These field experiments, started in 1888 on a Putnam silt loam soil, deal with crop rotation, manure, and fertilizers. As indicated by the data in Table 9, the yields of wheat on plats 2 and 10 have averaged about the same during the period of 1914 to 1928. Plat 2 received commercial fertilizer, while plat 10 received manure annually. The CO_2 produced by the two soils was almost identical during the first 24 hours, but during the next 24 hours the manure plat produced about three times that of the commercial fertilizer plat. This may have been a result of nutrients from the manure becoming available during the second 24-hour period. Plat 9, untreated, yielded about one-half as much grain as plats 2 and 10 and its soil produced in 24 hours only one-third as much CO_2. All these plats had grown wheat continuously.

Table 9.—*The effect of various soil treatments on the production of CO_2 and the average yield of field crops for the period 1914 to 1928, Putnam silt loam, Sanborn Field, Missouri.*

Plat No.	Field treatment	Production of CO_2, mgm		Yields per acre of various crops				
		0-24 hours	24-48 hours	Corn, bu.	Oats, bu.	Wheat, bu.	Clover, lbs.	Timothy, lbs.
2	N, P, and K annually equal to that in 40 bushels of wheat	52.9	64.7	—	—	20.65	—	—
9	None	18.5	44.3	—	—	10.19	—	—
10	Manure annually	54.1	189.1	—	—	20.71	—	—
17	None	21.8	31.9	19.03	—	—	—	—
18	Manure annually	112.0	85.8	34.91	—	—	—	—
21	Manure to 1913; since, 200 pounds superphosphate	32.6	49.9	—	—	23.41	—	—
22	Manure annually	44.4	117.0	—	—	—	—	5,367
23	None	19.0	32.3	—	—	—	—	1,944
24	Manure to 1913, nothing since	30.2	51.4	—	—	18.35	—	—
29	Manure 1908-1913; ammonium sulfate since	15.4	64.5	—	—	13.36	—	—
30	Manure to 1913; $NaNO_3$ since	22.4	52.0	—	—	19.23	—	—
35	Manure to 1913; nothing since	15.3	50.8	55.79	43.47	27.55	3,430	5,828
36	Manure to 1913; 150 pounds 3-10-4 annually since	19.3	54.3	—	—	20.50	—	—
37	Manure to 1913; 3-10-4 on corn and wheat since	25.7	83.1	56.22	48.35	32.84	5,194	6,610
38	Limestone and manure to 1913; 3-10-4 on corn and wheat since	62.6	68.8	59.15	48.29	31.25	5,537	6,080

Plat 29 received manure from 1908 to 1913 and plot 30 received manure from 1889 to 1913. Since 1913, plat 29 has received $(NH_4)_2SO_4$, whereas plat 30 has received an equivalent quantity of $NaNO_3$. The soil from the $NaNO_3$ plat produced nearly 50% more CO_2 during the first 24 hours, and this plat produced nearly 50% more wheat for the 1914 to 1928 period. The differences are not entirely due to the fertilizer treatment, but they should be largely due to it. The production of CO_2 for the first day by the soil from these plats was about the same as that of the no-treatment plats growing the same crop continuously; but on the second day, the no-treatment plats produced significantly less CO_2.

Plats 35, 37, and 38 received manure until 1913, after which the manure was discontinued; and since then, plats 37 and 38 have received a 3-10-4 fertilizer on corn and wheat. Plat 38 has had lime. The addition of a 3-10-4 fertilizer increased the crop yields and CO_2 production. Lime increased the production of CO_2, but it had little effect on the yield of the crops. The fertilizer had its greatest effect on clover production.

Some of the soil samples obtained from Sanborn field were used in a study of the effect of rotations on CO_2 production by the soil microorganisms. As shown by the data in Table 9, plats 9 and 17 were untreated continuous wheat and corn plats, respectively. The production of CO_2 by soils from these plats was low and about equal during the first 24 hours, but during the second 24 hours the CO_2 production of the wheat soil was higher than that for the corn soil. Soil from plat 23, a continuous untreated timothy plat, produced practically the same quantity of CO_2 as did soil from the continuous corn plat.

Soils from three manured plats, plats 10, 18, and 22, which had grown wheat, corn, and timothy, respectively, produced 54, 112, and 44 mgm of CO_2 on the first day and 189, 86, and 117 mgm, respectively, on the second day. It seems logical to attribute changes in the relative production of CO_2 to differences in the quantity of nutrients made available by the different plats. A part of these differences may have been due to the cultural practices used in growing the different crops and to the methods of application of the manure.

Fertility Plats, Hillsdale sandy loam.—Samples of soil were collected in the fall of 1934 on a series of plats which were laid out in 1930 at the Michigan Experiment Station to determine the effect of phosphorus on the yields of grain. Among the treatments were applications of 3-48-10 and 3-0-10. In 1933, each of these plats had been divided and an additional 30% of nitrogen added to one-half of each plat. The yields obtained during the last two years were slightly greater where phosphorus was applied and the production of CO_2 was greatly increased by the field application of phosphorus. When the soil, which was unphosphated in the field, was treated with phosphorus in addition to nitrogen in the laboratory, CO_2 production was increased, but this was not the case when soil which was phosphated in the field was so treated in the laboratory. Increasing the nitrogen in the field from 3.0 to 6.0% decreased the production of CO_2 in the laboratory where nitrogen was applied. As mentioned elsewhere in this paper, this may have been due to an increased consumption of

other elements by the crop plants or to a reduction in the Azotobacters (15, 16).

Fertility plats, Mississippi and Louisiana.—Certain studies regarding the effect of different phosphorus carriers and lime on the yields of cotton[4] and on the production of CO_2 by the soil are reported in Table 10. When used without lime, basic slag produced higher yields of seed cotton and more CO_2 than any other phosphorus carrier, but with lime superphosphate was more effective than the basic slag. Rock phosphate was decidedly inferior to the other phosphorus carriers both with respect to yields of cotton and production of CO_2. The relative response of the soil micro-organisms to the carriers of phosphorus as indicated by CO_2 production and yields of cotton were similar on both the limed and the unlimed soil. There was probably an accumulation of lime in the field from the addition of basic slag.

TABLE 10.—*The effect of different phosphorus carriers and lime on the production of CO_2 and seed cotton in Norfolk fine sandy loam.*

Treatment*	CO_2 in 17 hours, mgm	1931 32 average yield of seed cotton, lbs
NP*	147.2	440
NS	161.8	729
NR	108 1	378
NLP	170.8	855
NLS	166 6	766
NLR	136.8	665

*All plats received potash; N = 30 mgm of nitrate of soda; P = 25 mgm 20% superphosphate, R = rock phosphate; S = basic slag equivalent to the P_2O_5 in the superphosphate The maximum water-holding capacity was 30 cc, the water used was 17 cc

The relation between the response of cotton and of soil micro-organisms to superphosphate and their relation to the phosphorus content of the untreated soil, as indicated by Truog's method, is shown in Table 11. There were only 13 determinations. The correlation coefficient between the increase in crop yield due to superphosphate and the increase in the CO_2 produced due to superphosphate is .60 ± .176. The correlation coefficient between the increase in crop yield due to superphosphate and the phosphorus soluble in dilute acid is —.59 ± .181. The correlation coefficient between the increase in CO_2 due to superphosphate and the phosphorus soluble in dilute acid is —.40 ± .210. These correlation coefficients would not be considered to be very high if they were obtained using field data from one field, but when it is considered that the field data were taken from 13 different fields distributed over Mississippi and Louisiana and that different climatic and cultural conditions existed in each field, they indicate a rather significant relation between the field data and the two laboratory methods.

Dividing the dilute acid-soluble phosphorus by the combined silt and clay content, or the maximum water-holding capacity of the soil, increased the correlation coefficient of increases in yield of cotton and soluble phosphorus from —.59 ± .181 to —.70 ± .143 and —.63 ±

[4]Data collected by the writer at the Mississippi Experiment Station.

TABLE 11.—*The relation between the increase in CO_2 production and crop yield due to phosphorus and soluble phosphorus, as determined by Truog's method, and the use of the maximum water-holding capacity and silt + clay content of the soil in the interpretation of the data.*

Soil type	Soluble phos-phorus, p.p.m.	Increase due to phosphorus		Silt + clay, %
		CO_2, mgm*	Seed cotton, lbs.	
Houston clay	8.3	70	385	75.6
Ruston fine sandy loam (?)	10.0	52	174	56.8
Orangeburg fine sandy loam	35.8	7	33	27.8
Norfolk fine sandy loam	17.6	49	194	23.8
Oktibbeha clay	7.3	44	297	72.6
Sarpy fine sandy loam	105.5	15	—1	61.8
Trinity clay	94.0	7	77	63.6
Denham silt loam	8.4	16	50	66.8
Ruston fine sandy loam	13.1	7	145	34.3
Yohola very fine sandy loam	85.8	14	125	63.8
Ruston fine sandy loam	9.5	32	138	19.8
Ruston fine sandy loam	9.4	30	238	29.3
Memphis silt loam	4.2	18	409	64.8

*All cultures received 600 lbs. of $NaNO_3$ per acre

.167, respectively These data show that the heavy soils require a greater supply of dilute acid-soluble phosphorus than the light soils to supply the needs of cotton without the addition of superphosphate. The silt and clay content of the soil was determined by the Bouyoucos hydrometer method.

Fertilizers, greenhouse experiments.—Ellis (4) grew two crops of Sudan grass on the A_1, A_2, and B horizons of Conover loam, Hillsdale sandy loam, Bellefontaine sandy loam, and Miami loam in greenhouse pot cultures. By means of laboratory tests he maintained the same phosphorus, potassium, and nitrogen levels in each horizon and reported the yields obtained from each horizon under those conditions. Ellis found that the addition of a complete fertilizer to the A_2 and B horizons of all soil types studied, except the Hillsdale, resulted in first crop yields in excess of those obtained from the unfertilized A_1 horizon, but that for the second crop the untreated A_1 horizon gave a greater yield in all cases than that of any treatment of the A_2 and B horizons.

These soils were sampled and CO_2 production studies were made on them 6 months after the second crop was harvested. Therefore, the state of fertility of the soils as they were used in the laboratory was more nearly like their fertility during the growth of the second crop than that existing when the first crop was grown.

The data recorded in Table 12 show that the CO_2 production by the A_1 horizons of all four soil types was usually several times that by either of the other two horizons. In certain cases, the nitrogen potash treatment reduced the production of CO_2. In a few cases, the nitrogen-phosphorus treatment increased the production of CO_2.

TABLE 12.—*The yields of Sudan grass in pot cultures and the production of CO_2 by the A_1, A_2, and B horizons of several soils.**

Greenhouse treatment†	A_1 horizon: Crop yield, grams, 1st	A_1 horizon: Crop yield, grams, 2nd	A_1 horizon: CO_2, mgm	A_2 horizon: Crop yield, grams, 1st	A_2 horizon: Crop yield, grams, 2nd	A_2 horizon: CO_2, mgm	B horizon: Crop yield, grams, 1st	B horizon: Crop yield, grams, 2nd	B horizon: CO_2, mgm
				Bellefontaine Sandy Loam					
Ck	3.00	2.16	25.7	0.69	0.75	10.3	0.85	1.64	9.5
NK	2.55	2.51	26.5	1.19	1.45	8.0	0.88	1.20	6.7
NP	6.63	3.02	47.1, 33.2‡	2.71	1.02	9.9	3.23	0.80	8.4
KP	7.34	3.13	40.3	2.72	0.79	8.4	2.50	0.83	6.3
NPK	9.05	3.46	39.4	3.75	1.02	9.3	3.74	1.66	7.8
				Conover Loam					
Ck	3.29	6.15	46.0	2.35	2.11	27.7, 19.0‡	2.59	1.60	11.4
NK	6.19	10.00	41.9	2.76	4.53	16.5	2.55	2.06	10.8
NP	5.31	7.57	70.0	3.16	3.16	16.9	3.66	2.48	19.8, 11.9‡
KP	10.40	7.82	51.4	4.24	2.57	12.7, 21.2‡	2.70	1.64	13.9
NPK	10.74	10.01	51.3	4.71	3.58	13.7	3.63	2.31	10.4, 16.1‡
				Hillsdale Sandy Loam					
Ck	9.48	6.87	36.7	0.16	0.79	8.1	0.24	0.54	13.1
NK	12.68	8.49	33.4	0.23	0.28	8.0	0.19	0.26	9.2
NP	12.96	6.64	34.7	0.25	1.12	8.5	4.20	1.72	10.6
KP	14.28	6.86	29.5	1.44	0.66	6.9	0.75	3.63	8.8
NPK	14.61	7.10	34.1	2.61	1.30	7.7	3.94	2.52	8.4
				Miami Loam					
Ck	2.58	3.12	16.5	1.84	1.25	8.3	3.62	1.53	5.2
NK	1.83	2.38	12.7	0.22	0.57	5.2	0.78	1.06	1.1, 6.9‡
NP	14.29	4.53	29.3	4.74	2.51	14.5	5.96	1.80	8.0
KP	9.79	5.82	27.3, 18.7‡	4.40	1.64	10.4	4.78	1.10	2.7
NPK	15.16	5.05	27.2, 21.1‡	6.85	1.70	10.2	7.15	2.23	6.8

*The yields of Sudan grass were taken from Ellis' thesis (12).
†No fertilizer was applied to the cultures.
‡The CO_2 produced by soil from duplicate pots did not check closely.

Green manures.—CO_2 production studies were made on soils obtained from a series of green manure plats where comparisons were made between the effects of plowing under or removing sweet clover and rye. The field data show that both sweet clover and rye plowed under caused slight increases in yield, but the laboratory data showed that where only nitrogen was applied in the laboratory there was more CO_2 produced by the soil from the "sweet clover off" plat than by the soil from the "sweet clover under" plat. The plowing under of rye also suppressed the production of CO_2. The addition of phos-

phorus as well as nitrogen in the laboratory brought the production of CO_2 where rye and sweet clover were plowed under up to that where they were taken off. This indicates that the additional plant material where the crops were plowed under brought about a tie-up of the phosphorus or other plant nutrients. It is possible that the products derived from the additional organic material when it underwent decomposition covered up part of the colloidal fraction of the soil and thus hindered the normal exchange of calcium and phosphorus. Jenny and Shade (6) advanced the idea as an explanation of the variable results obtained by various research workers on the effect of calcium on the exchangeable potassium.

Because the sweet clover and rye plats were in different sections of the field, it was deemed unwise to make comparisons one with the other.

SUMMARY

A new procedure has been developed (2) to study the relation between crop response and response of micro-organisms to soil treatments and to varying fertility levels. The production of CO_2 is used as a measure of the response of micro-organisms and the procedure consists in treating soil with mannitol and determining the CO_2 at the end of 24 hours. The important feature of this procedure is that only a short time is required to make a test and only one CO_2 determination is necessary

In applying the CO_2 production method to a large number of soils which had received a great variety of treatments, the following points were brought out:

1. The production of CO_2 in soils to which mannitol had been added under controlled laboratory conditions tended to furnish a basis for measuring the nitrogen and phosphorus requirements of soils for cotton. There was a rather high correlation between the response of cotton to lime, phosphorus, and phosphorus and nitrogen and the production of CO_2 by mannitol-treated soils. Potassium, however, did not increase CO_2 production even where potassium gave increases in crop yields.
2. Micro-organisms (CO_2 production) responded to lime and superphosphate only when nitrogen was added.
3. Air drying increased the production of CO_2 on rewetting by some soils, but the results were not consistent.
4. On soils which were deficient in $CaCO_3$, the substitution of $MgCO_3$ for part of the added $CaCO_3$ did not consistently increase the production of CO_2.
5. Calcium arsenate had no effect on CO_2 production when used in large or small amounts, but intermediate quantities reduced it.
6. Superphosphate did not intensify arsenic toxicity to soil microorganisms nor did $FeSO_4$ alleviate the harmful effects of arsenic as measured by CO_2 production. This is contrary to crop response.
7. Soils deficient in copper, manganese, and zinc, as indicated by plant growth, showed no deficiency of these elements by this method.

8. Differences produced in soils by continuous fertilizer and cropping systems were demonstrated with the proposed method.
9. Certain soils were examined by this method which had been studied with the CO_2 production method using cellulose (3) as the energy material and a 24-day period. The data obtained with the mannitol method approached more closely the field data and with a great saving in time required to make the tests. Correlation coefficients between crop yields and CO_2 production are highly significant.
10. Results by the proposed method tend to correlate with crop response to soil treatment in some cases, but not in others. Further study is required to determine if these inconsistencies may be eliminated by modification of the procedure.

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COMPETITION BETWEEN COTTON VARIETIES IN ADJACENT ROWS[1]

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THE testing of cotton varieties is an activity common to all experiment stations in cotton growing regions and during the past 25 years much has been published on methods of conducting cotton variety experiments. The recommendations concerning experimental methods with cotton, including those of the American Society of Agronomy (7)[3], have, in most part, been in regard to size and shape of plat and to number of replications. Very little has been done with the problem of whether or not guard rows are necessary[4], and without information on this point it has been the general practice on Texas substations to use guard rows The plats consist, therefore, of three or of four rows, the inside one or two of which are harvested for yield. This procedure results in the loss of one-half or two-thirds of the area used since the outside rows of each plat are not harvested for yield data. It is generally accepted that an increase in the amount of replication is desirable, but at the same time it is recognized that enlarging the area involved in an experiment brings about an increase in variability due to additional soil differences. The omission of guard rows from plats affords the best opportunity of increasing replication without affecting the net size of plat or the size of the experimental area. This omission is justifiable provided there is no difference in competing ability among cotton varieties, or the differences in competing ability are so small as to be very minor sources of variability in the results when varieties are distributed at random.

During the years from 1927 to 1934, data have been gathered at the Texas substations located at Chillicothe and Angleton and at the main station farm at College Station to determine whether or not it is necessary to protect one variety from the competition of another by using guard rows, or, in other words, whether or not single-row plats can properly be used.

THE RESULTS

During the period 1927 to 1929, inclusive, the variety test at Chillicothe consisted of the same 48 varieties grown in quadruplicate plats. The test was on a different block of land each year. The plats consisted of four rows, each row being 1/168 acre in area, and each row was harvested separately. The sequence of varieties was constant

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[3]Figures in parenthesis refer to "Literature Cited," p. 278.

[4]After the manuscript of this paper had been completed, a paper dealing with this specific subject by N. I. Hancock and entitled "Row Competition and Its Relation to Cotton Varieties of Unlike Plant Growth" was published in this JOURNAL. (Vol. 28:948–957, 1936). As the two papers are in general agreement, we have not rewritten our paper to include a review of Mr. Hancock's results.

TABLE 1.—*Yields of seed cotton per row in pounds at Chillicothe, 1927 to 1929, inclusive.*

Row in plat	Variety	Protected or adjacent to	Yield of seed cotton per row in pounds												Total
			1927, replications				1928, replications				1929, replications				
			1	2	3	4	1	2	3	4	1	2	3	4	
3	Snowflake	Protected	10.9	7.6	10.1	9.4	5.3	3.3	3.6	3.7	3.5	4.2	3.1	3.2	67.9
4		Delfos	9.3	8.6	9.8	8.7	5.1	2.7	2.7	4.7	4.1	4.8	3.2	3.8	67.5
2	Delfos	Protected	11.7	11.8	12.6	11.2	5.5	3.5	3.2	5.5	5.4	5.3	4.3	4.2	84.2
1		Snowflake	10.0	12.0	11.7	10.4	6.6	3.4	4.4	5.7	4.5	5.3	4.2	4.2	82.4
3		Protected	11.0	11.1	11.1	10.3	6.1	4.0	3.4	6.7	5.8	6.0	5.3	4.6	85.4
3	Lightning Express	Protected	9.2	11.0	11.5	10.0	5.7	3.4	3.7	4.4	6.1	5.6	5.4	5.1	81.1
4		Acala	8.7	11.9	11.0	10.0	5.8	3.4	3.4	4.3	5.5	5.2	5.2	4.8	79.2
3	Acala	Protected	9.3	11.7	10.9	9.3	5.8	3.3	4.1	5.8	5.2	5.4	6.0	5.3	82.1
4		Trice	9.8	11.9	8.7	9.0	6.3	3.7	2.8	4.5	5.2	5.2	5.8	4.2	77.1
2	Trice	Protected	10.3	12.5	9.7	8.8	5.5	3.7	3.7	5.9	5.4	6.1	5.9	3.9	81.4
1		Acala	8.2	11.8	10.5	9.5	5.6	3.8	3.5	6.5	5.5	5.8	5.5	4.4	80.6
3	Bank Account	Protected	11.2	9.5	10.4	11.9	2.0	2.6	3.2	3.9	5.5	4.8	4.4	4.5	74.8
4		Westex	11.2	8.4	10.1	11.2	3.0	2.4	2.7	3.8	5.6	4.4	3.9	4.7	71.4
2		Protected	11.0	8.8	10.9	11.2	3.4	2.5	2.2	2.7	5.8	4.8	4.5	5.9	73.7
2	Westex	Protected	13.0	10.0	12.2	11.4	4.2	2.6	3.3	4.3	6.7	6.3	2.8	6.0	82.8
1		Bank Account	11.7	10.2	11.3	11.9	3.3	3.7	4.4	5.6	8.3	5.9	4.0	6.0	86.3
3	Rowden	Protected	7.7	9.7	11.0	8.2	2.5	1.9	3.0	2.1	5.5	6.6	3.8	4.5	66.5
4		Sunshine	7.3	8.5	9.4	10.3	2.3	2.7	2.1	1.4	5.7	6.3	4.2	4.6	64.8

2	Sunshine	Protected	9.0	11.6	11.1	11.0	2.9	2.2	3.9	2.6	7.1	6.3	4.5	6.0	78.2
1		Rowden	9.5	10.6	11.1	10.8	3.0	3.8	4.0	2.5	7.0	7.5	4.6	6.2	80.6
3	Sunshine	Protected	9.7	10.5	10.8	11.4	2.4	2.4	2.9	3.3	6.6	7.4	4.7	6.1	78.2
4		Cliett Superior	8.7	8.2	10.7	10.7	3.0	2.6	3.3	3.2	6.9	5.7	4.2	5.4	72.6
3	Cliett Superior	Protected	8.0	11.1	8.6	8.4	2.6	4.7	3.4	2.8	6.9	5.2	3.6	5.3	70.6
4		Blue Wagon	7.8	10.6	9.6	8.6	3.1	3.8	3.1	1.6	7.1	4.6	3.1	6.0	69.0
2	Blue Wagon	Protected	9.1	9.2	9.7	9.0	3.7	3.5	3.0	2.7	6.9	4.8	3.2	5.6	70.4
1		Cliett Superior	7.6	9.0	8.1	9.0	3.2	4.8	3.7	2.0	7.4	6.2	3.3	6.0	70.3
3	Blue Wagon	Protected	8.4	9.0	8.1	9.2	3.3	3.8	4.1	2.8	6.8	6.0	3.1	6.3	70.9
4		Mebane	8.5	9.9	9.7	9.0	3.0	4.7	4.0	2.0	6.8	5.3	3.8	5.5	72.2
2		Protected	9.1	9.2	9.7	9.0	3.7	3.5	3.0	2.7	6.9	4.8	3.2	5.6	70.4
2	New Boykin	Protected	9.5	11.3	12.1	11.7	3.5	3.9	3.4	3.9	7.6	4.9	4.8	6.5	83.1
1		Mebane	10.1	9.8	10.8	9.6	4.0	3.5	4.2	3.0	7.0	5.2	4.9	8.2	80.3
3	New Boykin	Protected	8.6	10.2	13.1	10.4	2.8	3.3	3.2	4.9	7.2	4.9	5.3	6.0	79.9
4		Kasch	10.0	10.1	12.9	11.8	3.8	3.8	2.4	5.7	7.4	4.5	5.2	6.8	84.4
2	Mebane 4120	Protected	11.0	11.1	11.5	10.5	4.5	3.8	3.2	4.3	6.5	4.5	5.2	6.4	82.5
1		Kasch	9.9	11.0	11.8	10.2	4.8	4.1	3.8	4.8	7.0	4.6	5.9	6.7	84.6
3		Protected	10.4	11.2	12.4	11.0	4.5	3.6	3.3	3.9	6.2	4.6	5.2	7.2	83.5
3	Mebane 4120	Protected	10.4	11.2	12.4	11.0	4.5	3.6	3.3	3.9	6.2	4.6	5.2	7.2	83.5
4		Mebane 804	10.5	11.4	11.4	10.1	4.2	4.4	3.9	3.6	5.5	4.9	6.1	6.7	82.7
2	Mebane 804	Protected	10.1	9.9	10.0	9.6	4.1	4.4	3.0	3.1	6.1	5.1	5.9	7.1	78.4
1		Mebane 4120	8.9	10.3	11.5	10.1	3.6	4.0	3.4	5.7	6.7	5.8	5.6	7.5	83.1
2	Cleveland	Protected	12.0	11.9	11.4	11.5	3.7	4.0	1.9	2.7	6.1	5.0	5.3	6.5	82.0
1		Mebane 804	10.3	10.6	9.8	10.3	5.0	4.8	3.0	3.0	5.8	5.1	5.2	6.9	79.8
3		Protected	10.7	11.6	11.9	10.2	3.9	4.2	2.0	3.7	6.3	5.9	4.7	5.4	80.5

throughout the 3 years; therefore, a protected row of each variety grew adjacent to a row of the same variety subjected to competition from one side by a certain other variety 12 times during the 3 years. Careful note was made of skips in stand and after all rows with skips or rows adjacent to rows with skips were omitted from the results, only 19 populations of 12 pairs remained. The primary data are presented in Table 1.

These 19 comparisons of adjacent protected and unprotected rows of the same variety were analyzed by the variance method of Fisher (2), except that the F value of Snedecor (6) was used in place of Fisher's Z value to determine the significance to be attached to the variation due to the different sources. In Table 2 is presented a typical analysis.

TABLE 2.—*Sunshine—protected and adjacent to Rowden.*

Year	Replication	Yield, pounds of seed cotton per row x 10		
		Protected	Unprotected	Total
1927	1	90	95	185
	2	116	106	222
	3	111	111	222
	4	110	108	218
Total	—	427	420	847
1928	1	29	30	59
	2	22	38	60
	3	39	40	79
	4	26	25	51
Total	—	116	133	249
1929	1	71	70	141
	2	63	75	138
	3	45	46	91
	4	60	62	122
Total	—	239	253	492
3-year total		782	806	1,588

Table of variance.

Source of variability	Sum of squares	Degrees of freedom	Mean square
Total	24,361	23	———
Replication	1,481	9	164.6
Treatment	24	1	24
Season	22,612	2	11,306
Interaction, season and treatment	43	2	21.5
Error	201	9	22.3

We are particularly interested to know in the first place whether the production of the protected and unprotected rows differs significantly; and in the second place, whether or not the varieties compete differently in different years. The sources of variability we are interested in are, therefore, (a) treatment and (b) interaction of season and treatment.

In 18 out of the 19 comparisons, there were no statistically significant differences in production between adjacent protected and unprotected rows. In the remaining comparison the analysis showed that the average difference in production of 47 pounds of seed cotton to the acre between the protected and unprotected rows of Bank Account adjacent to Westex was statistically significant, being on the .03 level of significance. It is logical to think, however, that no significance should be attached to this case since there was no significant difference in average production between the other protected rows (rows 2) and these same unprotected rows (rows 4).

As regards interaction of season and treatment, in 15 cases there was no evidence that the varieties competed differently in the different years In three more cases, Delfos adjacent to Snowflake, Blue Wagon adjacent to Mebane, and Mebane 4120 adjacent to Kasch, although the production of the protected and unprotected rows did not differ significantly, there is indication that differences in behavior from year to year may have existed, the values being practically on the .05 level of significance. In one other case, Cleveland adjacent to Mebane 804, season-treatment interaction was statistically significant. However, if the other series of protected rows (rows 3) is used, the interaction is not significant and it appears that this isolated case in which there was statistical significance was due to chance. This being true, it is indicated that varieties compete against one another for moisture and plant food with the same effect in a good as in a bad year

The conclusion reached in this case is that varieties at Chillicothe do not differ in ability to compete for moisture and plant food. After this analysis was made it was still not known if a lack of difference in competing ability among varieties was generally true or applied only under the soil and climatic conditions existing at Chillicothe. Accordingly, an experiment was devised and carried out at Chillicothe, College Station, and Angleton during the years of 1933 and 1934. In this case three varieties of different type, and for convenience designated as early, medium, and late in maturity, were grown in all combinations in six replications for 2 years. In 1933, the varieties used were as follows: early, Westax; medium, Mebane; and late, Greer Wichita. In 1934, the varieties were changed in the belief that there were greater differences between Lightning Express as the early, Watson as the medium, and Greer Wichita as the late than existed between Westex, Mebane, and Greer Wichita. Size of plat was 1/200 acre at Chillicothe and 1/110 acre at Angleton and College Station.

The differences in yield of seed cotton per row in pounds per acre in favor of protected over unprotected rows which were subjected to

TABLE 3.—*Difference in yield of seed cotton in favor of protected over unprotected rows, pounds to the acre.*

Protected variety	Variety between rows of which the unprotected row occurred	Difference in yield of seed cotton in favor of protected over unprotected rows, pounds to the acre								P
		Replication						Total	Average	
		1	2	3	4	5	6			
		Chillicothe, 1933								
Westex (Early)	Medium	− 56	−188	−380	116	−252	−116	−876	−146.0	.05
Westex (Early)	Late	−292	−124	48	132	44	92	−100	− 16.7	.8
Mebane (Medium)	Early	8	4	− 24	−308	200	−204	−324	− 54.0	.4
Mebane (Medium	Late	−260	0	232	− 36	124	−284	−224	− 37.3	.7
Greer Wichita (Late)	Early	88	60	72	−136	156	7	247	41.2	.3
Greer Wichita (Late)	Medium	−196	352	− 24	−20	− 4	−149	− 41	− 6.8	.9
		Chillicothe, 1934								
Lightning Express (Early)	Medium	154	68	144	44	− 88	− 8	314	52.3	.6
Lightning Express (Early)	Late	44	124	−140	− 88	104	108	152	25.3	.8
Watson (Medium)	Early	−104	−100	32	− 60	− 64	− 52	−348	− 58.0	<.05
Watson (Medium)	Late	− 76	−124	−136	−232	92	84	−392	− 65.3	.7
Greer Wichita (Late)	Early	− 84	8	− 16	56	−184	12	−208	− 34.7	.3
Greer Wichita (Late)	Medium	− 76	− 12	12	8	− 24	132	40	6.7	.8
		College Station, 1933								
Westex (Early)	Medium	28	28	1	− 20	48	− 55	30	5.0	.7
Westex (Early)	Late	−184	36	76	− 6	179	− 7	94	− 15.7	.7
Mebane (Medium)	Early	110	96	−116	21	144	− 40	215	35.8	.4
Mebane (Medium)	Late	−267	138	14	0	158	−212	−169	− 28.2	.7
Greer Wichita (Late)	Early	165	− 90	58	− 40	82	−152	23	3.8	.9
Greer Wichita (Late)	Medium	138	28	−103	42	6	− 62	49	8.2	.8

				College Station 1934						
Lightning Express (Early)	Medium	6	35	48	27	130	−103	−253	− 42 2	8
Lightning Express (Early)	Late	118	1	27	81	82	−193	−264	− 44 0	3
Watson (Medium)	Early	48	104	55	111	26	179	471	78 5	< 05
Watson (Medium)	Late	63	18	60	63	9	178	− 1	− 2	9
Greer Wichita (Late)	Early	70	28	12	28	56	268	154	25 7	6
Greer Wichita (Late)	Medium	83	21	27	62	− 21	137	19	3 2	9
				Angleton 1933						
Westex (Early)	Medium	5	168	127	95	369	369	59	9 8	9
Westex (Early)	Late	0	131	12	120	67	58	102	17 0	6
Mebane (Medium)	Early	253	10	8	66	19	190	414	− 69 0	2
Mebane (Medium)	Late	123	1	29	8	− 85	51	279	− 46 5	> 05
Greer Wichita (Late)	Earl	116	100	203	118	282	365	−342	− 57 0	6
Greer Wichita (Late)	Medium	73	1	162	243	176	−143	14	2 3	9
				Angleton 1934						
Lightning Express (Early)	Medium	54	163	36	27	26	18	162	27 0	4
Lightning Express (Early)	Late	67	16	107	93	103	35	389	64 8	02
Watson (Medium)	Early	37	48	79	18	37	− 38	− 87	− 14 5	4
Watson (Medium)	Late	67	60	46	142	117	50	270	45 0	2
Greer Wichita (Late) .	Early	5	25	1	127	19	54	83	− 13 8	6
Greer Wichita (Late)	Medium	110	65	22	6	63	− 39	7	1 2	9

competition from both sides by the same variety for each year at each of the three Stations are shown in Table 3. The maximum possibility for competition occurred in this study as a single row of one variety fell between rows of a single other variety. The data were treated by Fisher's (2) method for determining the significance of the mean of a unique sample. When analyzed in this manner, 31 differences were not statistically significant from 0, 4 differences were on the border line of significance, and 1 difference was statistically significant.

Differences that are statistically significant or approach statistical significance resulted when:

1. At Chillicothe in 1933 the unprotected rows of the early variety located between rows of the medium variety were greater in production than the protected rows, indicating that the early variety competed on more than even terms with the medium variety.
2. At Chillicothe in 1934 the unprotected rows of the medium variety located between rows of the early variety were greater in production than the protected rows, indicating that the medium variety competed on more than equal terms with the early variety.
3. At College Station in 1934 the protected rows of the medium variety were greater in production than the unprotected rows located between rows of the early variety, indicating that the production of the medium variety had been depressed by the adjacent early variety, or, in other words, that the early variety competed better than the medium variety.
4. At Angleton in 1933 the unprotected rows of the medium variety located between rows of the late variety were greater in production than the protected rows, indicating that the medium variety competed on more than equal terms with the late variety.
5. At Angleton in 1934 the protected rows of the early variety were greater in production than the unprotected rows located between rows of the late variety, indicating that the production of the early variety was depressed by the adjacent late variety, or, in other words, that the late variety competed better than the early variety.

These results are inconsistent and one is led to suspect that these differences, even though they approach statistical significance, are due to chance. Also, if these differences between protected and unprotected rows were the result of actual differences in competing ability between varieties, one would expect that when, as at Chillicothe in 1933, the early variety was benefited by its location between rows of the medium variety, the yield of the medium variety in that year would have been depressed when the medium variety was located between rows of the early variety. Such was not the case, however, in this or any one of the other four cases, indicating the lack of differences in ability to compete.

The conclusion arrived at from all of these results is that cotton varieties differ but little in ability to compete, that varieties compete the same in a favorable as in an unfavorable season, and that single-row plats can safely be used.

The conclusions arrived at from this work in Texas are not in agreement with those of Christidis (1) who concluded from work at the Greek Cotton Institute that, "The results . . . seem to suggest that competition may cause a definite bias in estimating the comparative yielding value of cotton varieties. Therefore, it appears advisable that field trials should be so arranged that competition effects between different varieties will be eliminated." Christidis further interpreted his results as showing a variation ascribed to competition which varied with variety from 0 to ±6% of the mean. In view of the discrepancy between the conclusions of Christidis and those arrived at from our studies, we have treated his data in a manner different from his with the results shown in Table 4.

TABLE 4.—*Data from Greek Cotton Institute, table of variance for a-b rows.**

Source	Degrees of freedom	Sum of squares	Mean square	F value	
				Tabulated	Calculated
Total	89	184.6920	—	—	—
Between rows	8	22.0377	2.7547	2.06	1.3717
Within rows (exp. error)	81	162.6543	2.0081	—	—

*"a" rows were unprotected and "b" rows were protected

*Table of variance for b-c rows.**

Source	Degrees of freedom	Sum of squares	Mean square	F value	
				Tabulated	Calculated
Total	89	83.0046	—	—	—
Between rows.	8	12.7293	1.5349	2.06	1.7681
Within rows (exp. error)	81	70.3153	.8681	—	—

*"b" rows were protected and "c" rows were unprotected.

The calculated value of F would have to be greater than 2.06 in either case before significance could be attached to the results.

The mean difference in production between unprotected rows "a" and the protected rows "b" is, therefore, without statistical significance and likewise the mean difference between rows "b" and rows "c". In other words, in this variety test, where the varieties were distributed at random, one would be justified statistically in using either one of the unprotected rows in place of the protected rows in comparing the varieties Thus the data of Christidis, if considered in this way, instead of conflicting with our own, point to the same conclusion, namely, that competition is not an important factor in cotton variety tests and that single-row plats can safely be used.

DISCUSSION

Although we were unable to establish the existence of differences in competing ability among cotton varieties,[5] it is possible that they

[5]In the paper cited in footnote 4, Hancock presents data to show that Acala has the ability to compete to the detriment of Delfos.

may exist. In view of this possibility, and if single-row plats are used, it is important to randomize the planting of varieties so that it will be an infrequent occurrence when the same two varieties will appear adjacent more than once in 1 year.

If the use of single-row plats is adopted, good stands, which are desirable in any case, become essential if results are to be accurate. It not infrequently happens, however, that good stands cannot be obtained on every plat, usually because of poor germinating ability of a particular lot of seed. In such a case a random distribution of varieties tends to minimize the effect on adjacent varieties of the poor stand obtained with one variety but, of course, randomization will not benefit the variety having a poor stand.

As a general rule, the requirement of good plat technic most difficult to meet is that of sufficient replication. The use of single-row plats instead of three- or four-row plats allows for a two- or a one-fold increase in the number of replications without changing the net size of plat or the total area of the experiment and makes the requirement of adequate replication easier to meet.

It seems desirable at this point to set forth the experimental methods of testing cotton varieties which have been adopted by the Texas Station. Single-row plats of 1/110 acre or more are used (5). The varieties are distributed at random in at least six replications (5). Yields are computed to pounds of lint and this figure is computed by multiplying seed cotton yield by a figure of lint percentage derived from ginning a single representative sample of seed cotton drawn from the production of a single plat (3, 4, 8).

SUMMARY AND CONCLUSIONS

The results of studies at three Texas stations indicate that, as a general rule, cotton varieties grown in variety tests in Texas do not differ in ability to compete for moisture and plant food. It is desirable, therefore, to use single-row plats and to use the land saved in so doing for additional replications. Although differences in competing ability were not found, they may conceivably exist, and in view of this possibility and if single-row plats are adopted, a random distribution of plats is not only desirable, it is essential. When single-row plats are used good stands are necessary if results are to be accurate.

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THE INFLUENCE OF SOME CLIMATOLOGICAL FACTORS ON SEED-STALK DEVELOPMENT AND SEED YIELD OF SPACE-ISOLATED MOTHER BEETS[1]

H. L. KOHLS[2]

VARIATION in the percentage of sugar beets that produce seed stalks and in the yield of seed per plant has been observed from year to year at the Michigan Agricultural Experiment Station. Part of the variation was explained by inherited differences between plants (7)[3], but the factors involved appeared to be very complex. Seed stalk development has been reported as an inherited character (9, 4, 1), and environment, as well as heredity, plays an important part in the variation of this character (4).

Several climatological factors are apparently influential in seed stalk development and seed production of sugar beets, the principal ones being temperature, precipitation, and relative humidity. The purpose of this article is to present data which may clarify some of the relationships between certain climatological factors and seed stalk development and seed yield as they exist at East Lansing, Mich.

MATERIAL AND METHODS USED

The mother sugar beets were those used in the regular breeding program of the Michigan Experiment Station and were stored in a root cellar where the temperature was kept fairly constant, between 35° and 40° F. The roots were packed in moist sand, except the last 2 years when they were dipped in paraffin and stored in open potato crates. The beets were isolated by space in Lansing and neighboring towns as described by Down and Lavis (3) and had to depend upon local showers for moisture.

The mother beets were inbred from zero to five generations and inbreeding and selection undoubtedly had some influence on seed yield (6). The yields were therefore weighted in an attempt to eliminate this effect. No correction was made for influence of inbreeding on percentage of plants that produced seed stalks as there seemed to be no differential effect due to inbreeding within a given year. The data for seed yield do not include beets that did not produce seed. The data on seed stalk production include all living beets whether they produced seed stalks or not. Seed stalk development means, in this article, elongation of the plant axis which may or may not show flowering parts. The data are for 9 years, 1926 to 1935, except 1928, which was omitted because there appeared to be an inaccuracy in the record of seed weights. The number and percentage of beets that produced seed stalks and yield of seed per plant are shown in Table 1.

Climatological data were obtained from the U. S. Dept. of Agriculture. Weather Bureau, East Lansing, Mich., and included maximum, mean, and minimum temperatures; precipitation; relative humidity at 8:00 a. m., 12:00 noon, and 8:00 p. m.; and number of hours of sunshine per day. The growing

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[3]Figures in parenthesis refer to "Literature Cited", p. 285.

TABLE 1.—*Percentage and number of beets that produced seed stalks and yield per plant.*

Year	No. with seed stalk	Per cent with seed stalks	Grams of seed*
1926	95	95.00	25.12
1927	112	94.12	24.14
1929	118	76.63	20.74
1930	431	99.08	33.32
1931	427	99.53	22.08
1932	315	92.92	18.67
1933	199	94.31	24.04
1934	81	65.85	18.17
1935	175	94.09	31.26
Av. per year	217	90.17	24.17

*Only plants that produced seed are included

season was divided into half-month periods to make possible a more accurate determination of when each climatological factor was of greatest influence (Table 2).

TABLE 2.—*Average climatological data at East Lansing, Mich., for the nine years 1926 to 1935, with the exception of 1928.*

Period	Temperature in degrees Fahrenheit			Precipitation, inches	Relative humidity			Hours of sunshine
	Max.	Mean	Min.		8 a.m.	12 noon	8 p.m.	
April 16 to 30	57.50	46.80	35.43	1.47	78.00	54.80	63.03	8.52
May 1 to 15	64.92	54.26	43.54	1.78	80.82	58.97	69.76	8.60
May 16 to 31	69.37	57.98	46.51	1.68	76.66	53.58	66.03	10.60
June 1 to 15	74.86	62.92	52.37	1.19	77.72	54.43	66.96	11.28
June 16 to 30	80.11	68.41	57.18	1.42	81.44	56.49	67.28	11.23
July 1 to 15	81.44	70.10	58.82	1.06	79.23	53.68	63.13	11.57
July 16 to 31	85.38	73.26	61.27	0.77	78.17	49.46	59.37	11.98
Aug. 1 to 15	81.40	69.83	58.22	1.00	83.41	53.42	63.77	9.92
Aug. 16 to 31	78.80	67.21	53.33	0.67	86.09	48.59	64.16	9.86

Data on the influence of date of planting mother beets on percentage of plants that produced seed stalks and yield of seed were not available. The date of planting varied with the season but was always as early as possible without danger of freezing the roots or the ground being too wet. The first day of isolating varied from April 7, in 1930, to May 1, in 1934. All the roots were usually planted April 16 to 30.

Simple coefficients of correlation were calculated between the percentage of beets that produced seed stalks and yield of seed and each of the climatological factors for each period. Certain partial coefficients of correlation were calculated between factors where a relationship appeared to exist. Fisher's (5) table of values for correlation coefficients for different levels of significance were used in interpreting the data.

RELATIONSHIPS OF WEATHER FACTORS TO PERCENTAGE OF BEETS THAT PRODUCED SEED STALKS

The simple coefficients of correlation between the percentage of beets that produced seed stalks and maximum, mean, and minimum temperatures for April 16 to May 15 were small and not consistent in sign, which indicated that the temperature during that period was ineffective (Table 3).

TABLE 3.—*Coefficients of simple correlation between climatological factors and percentage of beets that produced seed stalks.*

Period	Temperature			Precipitation	Relative humidity			Hours of sunshine
	Max.	Mean	Min.		8 a.m.	12 noon	8 p.m.	
April 16 to 30...	.187	−.231	.318	−.032	.134	.338	−.073	−.152
May 1 to 15.	−.035	.007	.132	−.014	.313	.207	.569	−.075
May 16 to 31..	−.643	−.476	−.174	.898	.518	.608	.561	−.698
June 1 to 15..	−.369	−.234	−.034	.501	.366	.583	.634	−.380
June 16 to 30.	−.175	−.203	−.120	.084	.141	.119	.314	.229

From Fisher's (5) table of values for correlation coefficients for different levels of significance when N is 7, the 5% point is .666, the 2% point is .750, and the 1% point is .798.

The temperature from May 16 to June 30 was too high for good seed stalk development as all coefficients were negative even though small and not significant. This was in agreement with Chroboczek (2) who concluded that cool temperature stimulated seed stalk development.

The precipitation from April 16 to May 15 was ineffective, but more precipitation was highly desirable from May 16 to June 15 to encourage rapid plant growth and to keep the temperature low.

High relative humidity was associated with seed stalk development for each of the three periods of 8 a.m., 12 noon, and 8 p.m. from April 16 on through June as the coefficients were all positive except —.073 at 8 p.m. April 16 to 30, even though they were below the 5% level of significance.

There was a tendency for too much sunshine from April 16 to June 15, particularly during the last half of May.

These climatological factors are, no doubt, interrelated. To separate effects, partial coefficients of correlation were calculated between these factors and periods that gave the largest simple coefficients of correlation.

The largest simple coefficient of correlation involving temperature was maximum temperature for the last half of May and was —.643. For the same period, precipitation gave a coefficient of .898. The partial coefficient for that period between percentage of beets that produced seed stalks and maximum temperature, holding precipitation constant, was —.794 which emphasizes the necessity of low

temperature for good seed stalk production. The partial coefficient of correlation for precipitation, holding maximum temperature constant, for the same period was .937, which indicated that high precipitation was more important than low temperature.

Relative humidity appeared to be associated with precipitation and this resulted in low coefficients of partial correlations between percentage of seed stalks and relative humidity for all periods when precipitation was held constant.

The hours of sunshine, also, appeared to be associated with precipitation as the coefficients of simple correlation were usually opposite in sign and of about the same magnitude.

RELATION OF WEATHER FACTORS TO YIELD OF SEED

In general, the temperature from April 16 to May 15 was ineffective for seed production. From May 16 to July 15 the temperature was too high as all the signs (Table 4) were negative. This is in agreement with Stewart (8) who suggested that a high temperature during the flowering period may cause low yields. The trend of the coefficients from July 16 to August 31 indicated that a warmer temperature would have been more desirable for seed production.

TABLE 4.—*Coefficients of simple correlation between climatological factors and seed yield.*

Period	Temperature			Precipitation	Relative humidity			Hours of sunshine
	Max.	Mean	Min.		8 a.m.	12 noon	8 p.m	
April 16 to 30.	-.288	-.363	.087	-.052	.741	.745	.484	-.407
May 1 to 15.	-.001	.073	.164	.156	.225	.147	.119	.049
May 16 to 31.	-.745	-.665	-.456	.333	.238	.317	.265	-.634
June 1 to 15. .	-.228	-.011	-.148	.357	-.106	.008	.314	-.550
June 16 to 30. .	-.533	-.455	-.287	.450	.244	.476	.528	-.315
July 1 to 15. .	-.408	-.269	-.057	-.738	.255	.365	.188	-.327
July 16 to 31. .	.239	.395	.460	.200	-.035	.246	.327	-.226
Aug. 1 to 15. .	.437	.374	.262	-.048	-.296	.024	-.141	-.024
Aug. 16 to 31.	-.098	.375	.621	-.246	.550	.255	.250	-.504

From Fisher's (5) table of values for correlation coefficients for different levels of significance, when N is 7, the 5% point is .666, the 2% point is .750, and the 1% point is .798.

Low precipitation during the last half of April and August was preferable, while during May, June, and the last half of July more precipitation than the average favored heavy seed yields. The large negative coefficient for the first half of July, the flowering period, indicated that rainfall may have interfered with pollination.

Relative humidity, in general, seemed ineffective, but there was some evidence that higher relative humidity may be more desirable,

particularly in the last half of April, as the coefficients are large and positive.

Less hours of sunshine appeared, in general, to be more desirable particularly during the last half of May and the first half of June.

The partial coefficients between seed yield and temperature were not significant for any of the periods, but the trend was the same as for the simple correlations and further indicated that the temperature from May 16 to July 15 was too warm for high seed yield.

Precipitation, holding maximum temperature for July 1 to 15 constant, gave a coefficient of partial correlation of —.692, which was close to the simple correlation of —.738. Precipitation, no doubt, should be below average during the flowering period, July 1 to 15, for high seed yield.

Relative humidity during the last half of April appeared to be associated with yield. The reason for this is not clear, for when seed stalk development and precipitation were held constant, the coefficients of partial correlation were .725 and .824, respectively, and are in agreement with the simple correlations.

The hours of sunshine did not affect seed yield except indirectly through precipitation. There appeared to be a negative correlation between hours of sunshine and precipitation.

The eight climatological factors studied tend to affect both the percentage of beets that produce seed stalks and yield of seed in the same manner and degree. This is shown in comparing Tables 3 and 4 where of the 40 possible comparisons only 6 are of opposite sign and in no case were they significantly different from each other in magnitude. The factors for July and August, though not affecting the percentage of beets that produce seed stalks, have a great influence on the yield of seed. (In Table 5 is shown the stages of plant development at various periods of the growing season.)

TABLE 5.—*Stages of plant development at various periods of the growing season.*

Period	Stages of plant development
April 16 to 30	A few of the earliest beets have small leaf growth.
May 1 to 15	All beets are up and leaves are 4 to 8 inches long.
May 16 to 31	A few plants are showing seed stalk development.
June 1 to 15	Seed stalks are a few inches to two feet in length.
June 16 to 30	Early plants are beginning to flower.
July 1 to 15	A majority of the plants are flowering profusely.
July 16 to 31	A few plants are flowering, all are setting seed.
Aug. 1 to 15	All plants are setting seed, a few are ready to harvest.
Aug. 16 to 31	A majority of the plants are ready to harvest.

The size of the seed stalk is not involved in the correlations involving the percentage of beets that produced seed stalks, but is an important factor in determining the amount of seed which can be produced. The effect of climatological factors on the size of the seed stalk, however, is reflected somewhat in the correlations between climatological factors prior to the appearance of flowers and final seed yield.

SUMMARY

A study of the influence of climatological factors upon the percentage of beets that produced seed stalks and seed yield of space-isolated mother beets was made at East Lansing, Mich. The data were for 9 years and were divided into half-month periods.

In general, the coefficients of correlation did not exceed Fisher's 5% point. A few coefficients did exceed the 5% and even the 1% points and these are considered to indicate critical periods in plant development.

The periods and weather conditions most favorable to a high percentage of beets with seed stalks were found to be a cool (less than 69.37° F maximum temperature), wet (more than 1.68 inches of rain), cloudy (less than 10.6 hours of sun per day) May 16 to 31, with similar weather extending into the last half of June.

The periods and weather conditions most favorable to a high yield of seed are the same periods and conditions that are especially favorable for seed stalk development and a cool (less than 81.44° F maximum temperature), dry (less than 1.06 inches of rain) July 1 to 15.

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THE PRODUCTION OF MACROSCOPIC COLONIES ON PLAQUES OF SOIL[1]

J. K. WILSON[2]

THE occurrence of Azotobacter in soils was observed by Beijerinck in 1901. This aerobic nitrogen-fixing organism was considered to be of exceptional value in the accretion of nitrogen in the soil. Its response to fertilizers and to soil amendments indicated that many of the conditions favoring its growth paralleled the conditions favoring the growth of higher plants. It has been suggested that this relationship might be used as a means of forecasting the fertilizer requirements of soils for higher plants. Many investigators have studied the distribution of the organism and conditions favoring its growth with that end in view.

Remy (1)[3] was an early worker in this field. He devised a method for the production of macroscopic colonies on plaques of sand. He used sand in a petri dish which was moistened with a solution containing mannito tol and certain salts. After sterilization, the surface of the plaque was inoculated by pouring on it a suspension of the soil under investigation. If suitable conditions were effected and the organisms were present, colonies were visible in a few days on the surface of the plaque. Many of these subsequently turned black.

Schneider (4) modified this method by placing a thin layer of soil in contact with the surface of the sand and by providing a form of capillary sub-irrigation.

Remy (2) accepted this modified method and used it in an attempt to correlate the growth and activities of Azotobacter in the soil with the yields of various crops. He observed when using this modified method that macroscopic colonies may develop in 24 hours if conditions are favorable.

Winogradsky (5) was impressed by this method of producing macroscopic colonies and by the possible relationship of the results to the economic application of fertilizers in crop production. He modified and developed the method more fully, and suggested that his modifications be employed and that the data thus obtained be used as a basis for making fertilizer applications to soils. Briefly, his improvement in the method consisted in the intimate incorporation of certain soil amendments and a carbohydrate with the soil and the addition of enough water so that when the soil was kneaded thoroughly, a moist pasty combination was obtained which could be molded in a suitable container. Such preparations or plaques were incubated in a moist chamber at 28° to 30° C. The first examination of such plaques was made after an incubation period of 24 hours, then subsequently as often as necessary in order to determine whether macroscopic colonies had developed. The response of the soil flora to various soil amendments was supposed to be a direct forecast of which nutrients

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication December 26, 1936.
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[3]Figures in parenthesis refer to "Literature Cited", p. 292.

should be applied, it any, to a particular soil in order that it might grow field crops successfully. When using this method compounds such as potassium di-hydrogen phosphate and calcium carbonate were employed, the object being to find a fertilizer salt or a combination of soil amendments that would induce macroscopic growth.

As soon as the improved spontaneous-culture method which Winogradsky employed was published it was widely adopted by workers. When the method was employed using soils of New York, it was soon observed that numerous soils were either deficient in organisms that would form macroscopic colonies on the plaques or that the conditions required for growth of colonies had not been provided. This condition was evident even though the soils had been fertilized with nutrient salts sometime previous to sampling. It was uncertain whether this failure to obtain colonies was due to the absence of certain organisms or to a deficiency of basic material in the soil or to some other condition. Certain phases of this complex problem have been investigated. This paper, therefore, details attempts to produce colonies on plaques of soil by incorporating with the soil various salts, either separately or in combination with certain other soil amendments. It is hoped by such studies that a satisfactory method may be developed for the soils of New York which can be used to indicate whether a soil is deficient in certain constituents for crop production.

SOILS EMPLOYED IN THE INVESTIGATION

The samples of soil employed in this investigation came from widely separated counties in New York State. The majority came from fields that were under cultivation, or have been cultivated in the past. Samples of 88 soil types representing 48 soil series were obtained from Erie County; from 28 soil types representing 14 soil series from Delaware County; and from 30 soil types representing 15 soil series from Nassau and Suffolk counties on Long Island. The largest number of samples from any one type was 12. These were from Sassafras loam and came from Long Island. The total number of samples of the 77 soil series or 146 soil types was 366. Only two of these samples were classed as peat. The rest were mineral soils and ranged all the way from dune sand to loams and clays. They were collected during the summer months of 1933 and were composites of borings taken from the first 6 to 7 inches of the surface soil. They were stored in paper cartons from which portions were taken for the investigation. Care was exercised throughout the taking and the handling of the samples to prevent contamination of one soil with another, although no strict aseptic methods were followed. The soils appeared to be air dry when employed in the tests. In this condition they were pulverized somewhat so that a representative quantity from each could be obtained. This was employed in a determination of the reaction of the soil and as material from which the plaques were made. The reaction of the samples was determined potentiometrically, using a quinhydrone electrode.

PRESENTATION OF DATA

The data for the most part are presented in their relation to the pH of the soils. In Table 1 the reactions of the 366 samples of soil are shown. They begin at pH 4.5 and extend to pH 8.5 with intervals of

0.5 pH between these extremes. The number of soils that fall in each group is given. The various salts or amendments employed in an effort to obtain a suitable environment for the development of macroscopic colonies and their effect on the same are given.

TABLE 1.—*Influence of soil amendments on the development of macroscopic colonies on plaques of soil with saccharose as source of energy.*

Amendment and influence on growth	pH groups and number of samples of soil in each group								
	4.5–5.0, 62	5.0–5.5, 151	5.5–6.0, 69	6.0–6.5, 36	6.5–7.0, 26	7.0–7.5, 8	7.5–8.0, 8	8.0–8.5, 3	Total, 366
None	23*	43	31	17	19	5	8	3	149
Improved by $CaCO_3$	31	46	14	5	2	1	3	1	103
Suppressed by $CaCO_3$	5	15	18	10	12	1	8	3	72
Improved by K_2HPO_4	45	108	45	15	12	4	4	2	235
Suppressed by K_2HPO_4	5	6	6	2	7	-	2	–	28
Larger growth by $CaCO_3$ and K_2HPO_4	37	58	23	8	7	3	3	–	139
Suppressed by $CaCO_3$ and K_2HPO_4	9	23	11	12	9	1	3	1	69
K_2HPO_4 and $CaCO_3$ induced growth	3	11	2	2	2	–	–	–	20
$MgNH_4PO_4$ induced growth on all plaques when above amendments failed	3	21	4	2	1	1	–	–	32

*Numbers indicate how many soils of the total in the group were affected by the amendment so that colonies were observed.

It should be mentioned that each of the 366 samples of soil contained organisms that produced macroscopic colonies. Some of the samples appeared to contain a larger population than others. But since it was not certain that the optimum conditions for growth of organisms was obtained in each instance, such a comparison was thought to be of little value. In 149 samples, or in about 40% of the soils, macroscopic colonies developed without the addition of an amendment. More than 65% of these 149 samples was lower in reaction than pH 6.0 and about 15% was lower in reaction than pH 5.0.

The growth of macroscopic colonies was improved by the incorporation of $CaCO_3$ in 103 of the samples of soil. This is about 28% of the entire number of samples and of this number about 5% were alkaline, about 12% had a pH value larger than 6.0, and 88% showed a pH value lower than 6.0. The complex necessary for macroscopic colony growth was not present in 217 of the 366 samples. This is about 60% of the cases. The necessary environment, however, was effected in 62 of these 216 samples of soils by incorporating $CaCO_3$ in the plaques. None of these 62 samples, which represent about 28% of those to which $CaCO_3$ was added, was alkaline and only 2 possessed a pH value higher than 6.0. The average pH value of the 62 samples of soil was 5.18.

In 72 cases the incorporation of $CaCO_3$ in the plaques as a soil amendment either reduced or completely suppressed macroscopic colony growth. This was noted in both acid and alkaline soils. The reduction was pronounced despite the fact that about 83% of the samples of soil which responded in this manner were acid and of these 52% were more acid than pH 6.0 and 27% more acid than pH 5.5.

The value of incorporating phosphorus in the plaques as a soil amendment is evident from Table 1. An improvement in macroscopic colony growth was evident in 235 samples or in 64%. In some cases improvement in colony growth was noted over that which was evident where only mannite was employed, or where $CaCO_3$ was incorporated in the plaques. The largest number of plaques of soil on which macroscopic colonies was evident and on which visible colony growth was effected by incorporating phosphorus as K_2HPO_4 was found among the most acid samples. The nutritional complex of the samples which possessed pH values between 4.5 and 5.5 was improved in 77% of the cases, while that of samples which possessed pH values between 6.0 and 7.0 was improved in only 43% of the cases.

The incorporation of phosphorus as a soil amendment reduced the number and size of macroscopic colonies in 28 samples of soil or about 8%. This was evident when the growth on plaques that received phosphorus was compared with that on plaques from the same samples that received no phosphorus. There is not enough of these samples in any pH group so that this depressive effect on growth could in any way be ascribed to the reaction of the samples. It is noteworthy that only two of the samples were decidedly alkaline. This could hardly be accounted for by a deficiency of phosphorus unless it was removed from the soil solution by a high precipitating action of the soil.

It was noted above that the incorporation of $CaCO_3$ or K_2HPO_4 in the plaques of soil may result in either increasing or decreasing the suitability of the soil complex for macroscopic colony growth. It is therefore important to know what effect the simultaneous incorporation of these compounds may have with respect to the development of macroscopic colonies. Such data are also presented in Table 1. It is apparent that a better environmental condition for the growth of macroscopic colonies was effected in plaques of the 139 samples of soils than was effected in similar plaques where either $CaCO_3$ or K_2HPO_4 was employed separately. The reaction of 68% of these samples of soils was more acid than that indicated by a pH of 5.5.

The combined effect of $CaCO_3$ and K_2HPO_4 as soil amendments on the growth of macroscopic colonies is further emphasized, for the incorporation of these two amendments effected a suitable nutritional environment for colony growth in 20 samples when each alone or mannite alone was ineffective. None of these 20 samples was alkaline and 70% were more acid than that represented by a pH of 5.5. It is striking that such a small number of samples out of 366 actually required both of these amendments to produce a suitable environment for these organisms.

It was noted where $CaCO_3$ was applied in the making of a plaque that it may have retarded or suppressed colony development; also that K_2HPO_4 may have acted similarly. It might be expected, there-

fore, that the simultaneous incorporation of these two soil amendments in a plaque may also retard or suppress the development of macroscopic colonies. Thus they were simultaneously employed in each of the 366 samples. The data show that there was a marked retardation in colony growth in 69 instances. This effect was not confined to the samples from either acid or alkaline soils, although about 80% of the samples were more acid than that represented by a pH of 6.5

It was observed also in testing these samples of soils for the presence of organisms that would form macroscopic colonies that 40% of the samples required no mineral amendment and that suitable conditions for the development of macroscopic colonies could be effected in about 55% more if $CaCO_3$ and K_2HPO_4 were separately or simultaneously incorporated when making the plaques. It was more difficult to demonstrate that such organisms existed in a thanetoid condition in in the remaining 5%.

Attempts were made to effect the proper environment by incorporating other salts when making the plaques. Compounds containing K, Mg, Mn, Na, Ca, and NH_3 as a chloride, a sulfate, a phosphate, or a nitrate were employed. The most effective individual salt was $MgNH_4PO_4$. This compound induced growth on the plaques from the remaining 5%, or 32 samples. One of these samples was neutral and the other 31 were acid.

After it was observed that $MgNH_4PO_4$ was effective in producing a suitable environment for the development of macroscopic colonies, it was employed in a test plaque of each of the 366 samples of soil. The results showed that it came nearest to universal efficiency of any salt or combination of salts that were tested. It was observed occasionally that this compound was no better than the di-potassium phosphate and in a few cases its use induced no better growth of macroscopic colonies than was found on a plaque from the same soil where only saccharose was employed. So far as could be readily ascertained it effected colony growth which was in every way similar to that produced by such compounds as $CaCO_3$ or K_2HPO_4. Other magnesium compounds did not produce the same effect. Calcium ammonium phosphate was also employed. Its value was compared with that of $MgNH_4PO_4$. It was valuable in a large number of cases, but it was not as effective as $MgNH_4PO_4$.

DISCUSSION AND SUMMARY

The development of colonies on plaques of soil is intimately associated with the nutrient requirements of the soil flora. When colonies appear it is proof that the nutritional requirements are at least partly fulfilled. If they do not appear it is usually possible to supplement the nutrients with a certain salt or salts and effect conditions so that colonies will appear on the plaques. It may be possible in a few instances that the required soil flora are absent. However, an extensive examination of samples of mineral soils did not indicate this condition.

In order to study the nutritional requirements of the soil flora so that macroscopic colonies could be produced on plaques that were made from these soils, 366 samples were collected. They represent 146 soil types or 77 soil series. The reaction of each sample was determined. Nineteen were alkaline and the rest were acid, 282 being more acid than that represented by a pH of 6. Each was used as material to make plaques of soil. These have yielded data, certain aspects of which should be emphasized.

The nutritional conditions were such in 16 of the alkaline soils and in 133 of the acid soils that macroscopic colonies developed without the addition of any inorganic material. These represent 40% of the soils. About 71% of the 133 acid soils were more acid than that represented by a pH of 6.

$CaCO_3$ was incorporated in a plaque that was made from each of the 366 samples. It improved colony growth in 103 instances. Improvement was noted in some instances where colony growth was observed without the addition of any inorganic material. The largest improvement was noted, however, among these samples that did not possess a suitable nutritional condition for colony growth In about 75% of those cases which were improved by incorporating $CaCO_3$ the samples of soil were more acid than that represented by a pH of 5.5. It improved colony growth in 5 of the 19 alkaline soils.

It should be emphasized also that macroscopic colony growth was suppressed in certain cases when $CaCO_3$ was incorporated in the plaques. This occurred in 12 of the 16 alkaline samples and in 60 of the 133 acid samples which possessed naturally a suitable environment for macroscopic colony gorwth. This suppression in 75% of the cases with alkaline soils and in only 45% of the cases with acid soils suggests that suppression occurs more frequently in alkaline soils than in acid soils. An explanation for this is not easily given.

The data obtained by incorporating K_2HPO_4 in the plaques may indicate that these soils are highly deficient in phosphorus. An application of phosphorus improved colony growth, however, in only 64% of the cases. It also suppressed colony growth in about 8% of the cases. Such suppressive action on colony growth was recorded by Sackett and Stewart (3). These workers suggest that the fertilizer added in making the plaques, together with that already present in such soils, appears to produce a concentration for bacterial growth either favorable when deficient or unfavorable when not deficient. Such suppressive effects may occur also when both $CaCO_3$ and K_2HPO_4 are simultaneously incorporated in making the plaques. This happened in about 19% of the cases reported in this study.

The fact that $MgNH_4PO_4$ never failed to effect a nutritional complex for macroscopic colony growth is outstanding in this work. Its function has been the object of considerable effort. Its exact effect has not been ascertained. It is suggested that it supplies a quickly assimilable nitrogen compound so that those organisms which from macroscopic colonies grow more readily and colonies appear before other organisms destroy the required environment. Efforts to establish this relationship, however, have always failed.

The response or lack of response of the microflora of the soil to the various salts that were employed in the plaques provide no direct forecast of which nutrients should be applied, if any, to a particular soil in order that it may grow field crops successfully. The favorable effect of $CaCO_3$ and of K_2HPO_4 on the development of macroscopic colonies when these materials are applied to soils that possess low pH values suggests that such soils may be deficient in these components, but since such compounds may depress colony growth, as well as having no visible effect at all, it is suggested that more information concerning the factors that favor colony development is necessary before the plaque method can be of much service in forecasting the deficiencies of the soils of New York for specific nutrients.

CONCLUSION

From a study of 366 samples of soil in relation to the production of macroscopic colonies on plaques of soil it is concluded that, if the proper nutritional condition is effected by soil amendments of one sort or another, macroscopic colonies will develop from the flora naturally present in the soil. Some salts appeared to be more effective in this respect than others. $MgNH_4PO_4$ came nearest to universal efficiency. When other salts commonly employed in such work failed to effect colony growth this salt was effective.

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AVAILABILITY OF PHOSPHATE ROCKS IN SOILS OF VARYING DEGREES OF ACIDITY[1]

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PHOSPHATE rocks have long been the principal source of materials for the production of soluble phosphates. Their use as a direct phosphate fertilizer however, has been limited because of their relative insolubility, and consequently many experiments have been conducted to determine the factors affecting the availability of phosphate rocks. This report is concerned only with experiments which were made to determine what influence the acidity of the soil might have on the availability of phosphate rocks from different sources and of varying chemical composition, particularly in their content of fluorine.

EXPERIMENTAL METHODS AND RESULTS

Experiments in the greenhouse were started November, 1934, with Clarksville silt loam soil of different degrees of acidity obtained from the Arkansas Experiment Station farm. The range in acidity, which covers that of most agricultural soils, was as follows: pH 4.33, pH 4.76, pH 5.07, pH 5.80, pH 6.82, and pH 7.14. None of the soils had received any phosphate fertilizer during the preceding 7 years. In these experiments, duplicate applications of phosphorus were made at the rate of 0.3 gram P_2O_5 per jar, containing 8 kilos of soil, as monocalcium phosphate, superphosphate, tricalcium phosphate, and the phosphate rocks of the composition given in Table 1.

TABLE 1.—*Composition of phosphate rocks.**

Material ground to 100 mesh	Percentage of P_2O_5		Percentage of F
	Total	Citrate-insoluble	
Curacao phosphate rock, No. 943	39.99	33.87	0.41
Curacao phosphate rock, No. 985	38.22	33.80	0.70
Christmas Island phosphate rock, No. 452	39.27	34.80	1.32
Nauru Island phosphate rock, No. 1160	38.66	33.97	2.10
Ocean Island phosphate rock, No. 451	40.15	37.51	2.97
Tennessee brown-rock phosphate, No. B-14	33.86	31.19	3.79

*The writer is indebted to K. D. Jacob, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, for the samples and analyses of the material given in this table.

Ammonium sulfate, sodium nitrate, and potassium chloride were added to each jar at the rate of 200, 100, and 300 pounds per acre, respectively. The jars were seeded with Sudan grass, thinned to a final stand of 11 plants per 2-gallon jar, watered with distilled water

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throughout the experiment, and kept at near optimum temperature. The results from the first cutting of Sudan grass are given in Table 2. In order to insure as near complete depletion as possible of the original available phosphorus in the soil before continuing the experiments, a further application of ammonium sulfate, sodium nitrate, and potassium chloride in solution was made on the stubble at a rate of 100 pounds per acre each and the Sudan grass permitted to grow. The results of the second cutting are given in Table 2.

After the second cutting, the soil in each jar was thoroughly mixed and a second application of phosphorus, nitrogen, and potasssium was made as described above. Sudan grass was again planted and the jars treated as before. The results from this crop are given in Table 3.

The results from the jars receiving nitrogen and potassium only show that the two cuttings of the first crop apparently removed most of the available phosphorus from the soil and that the Sudan grass in the second crop was feeding primarily on the phosphates added to the soil. Therefore, the results obtained from the phosphate rocks with the second crop should be a reliable indication of their availability in comparable soils with the range in acidity of those used in these experiments.

Following this crop the soil in each jar was again thoroughly mixed, another application of phosphorus, nitrogen, and potassium fertilizers made, and a third crop of Sudan grass was grown. The yields from this crop are also given in Table 3.

There are two ways in which the data can be compared, neither of which, however, show any definite relationship between soil acidity and availability of phosphorus in phosphate rocks. The first, which may be dismissed with little discussion, would be to take the yield from the application of monocalcium phosphate to the soil with a pH of 7.14 as standard and determine the relative yield of all the other treatments. This method, if the results are excluded from the soil with a pH of 5.80 which apparently contained considerable available phosphorus, shows a strong tendency towards a decrease rather than an increase in the availability of the phosphorus in the phosphate rock as the degree of acidity increases.

However, it would seem preferable, because of variations which may exist in soils, even though of the same type,[3] to compare relative yields for each soil on the basis of the yield of dry matter produced by the application of monocalcium phosphate. Since the results from this method of comparison are almost identical with those for a similar comparison of the amount of phosphorus absorbed by the plants from the different rocks, only a brief statement will be made here and the discussion will be presented with those results which will be found in Table 6.

The results from each of the three experiments show little evidence of a specific increase in amount of dry matter produced as the acidity of the soil increased. In the nearest approach to a definite relationship, sample 943 table 2, the field from the soil with a pH of 5.07

[3]DAVIS, F. L. A study of the uniformity of soil types and of the fundamental differences between the different soil series. Ala. Agr. Exp. Sta. Bul. 244. 1936.

TABLE 2.—*Average yield in grams of first crop of oven-dry Sudan grass hay grown in soils of varying acidity with nitrogen, potassium, and the phosphates indicated.*

Phosphate	pH 4.33		pH 4.76		pH 5.07		pH 5.80		pH 6.82		pH 7.14	
	1st cutting	2nd cutting	1st cutting	2nd cutting	1st cutting	2nd cutting	1st cutting	2nd cutting	1st cutting	2nd cutting	1st cutting	2nd cutting
None	8.4	6.6	10.9	11.3	9.7	8.5	16.7	11.4	5.6	8.2	4.0	5.8
Monocalcium phosphate	15.9	11.3	14.8	13.1	14.3	10.0	19.1	13.4	12.7	11.8	13.1	12.1
Superphosphate	16.8	11.6	15.0	14.5	15.6	10.5	18.5	14.1	13.3	10.9	13.8	12.6
Tricalcium phosphate	16.0	10.9	15.7	14.4	14.6	10.7	16.4	13.8	15.1	11.7	12.3	12.6
Phosphate rock 943	16.2	12.5	15.7	14.1	13.2	10.5	14.5	12.4	12.5	9.9	10.5	11.9
Phosphate rock 985	15.5	11.7	13.4	13.4	12.2	10.9	17.0	14.3	12.1	10.6	13.3	12.2
Phosphate rock 452	13.3	10.7	14.2	14.2	11.9	11.7	16.4	13.2	11.0	10.2	11.4	12.3
Phosphate rock 1160	13.4	11.0	12.7	11.2	8.5	11.3	13.2	12.1	11.2	11.5	11.6	12.6
Phosphate rock 451	11.7	10.0	13.1	12.2	6.1	11.6	15.2	14.3	9.5	9.5	10.0	11.4
Phosphate rock B-14	13.1	12.2	14.1	13.5	5.9	9.8	14.2	13.4	10.4	10.9	9.2	12.4

TABLE 3.—*Average yield in grams of second and third crops of oven-dry Sudan grass hay grown in soils of varying acidity with nitrogen, potassium, and the phosphates indicated.*

Phosphate	pH 4.33		pH 4.76		pH 5.07		pH 5.80		pH 6.82		pH 7.14	
	2nd crop	3rd crop	2nd crop	3rd crop	2nd crop	3rd crop	2nd crop	3rd crop	2nd crop	3rd crop	2nd crop	3rd crop
None	2.4	2.3	10.0	6.2	3.5	0.7	14.2	12.0	2.6	3.5	1.3	2.1
Monocalcium phosphate	11.6	7.0	13.7	13.7	16.9	9.5	24.7	19.1	17.3	13.7	22.9	12.7
Superphosphate	10.5	5.6	12.6	7.7	14.1	10.1	24.1	17.0	18.7	14.0	22.6	13.4
Tricalcium phosphate	13.2	6.9	14.5	11.1	14.5	7.3	25.3	16.2	18.0	11.4	19.6	10.8
Phosphate rock 943	11.1	7.7	12.8	10.5	14.2	7.3	24.2	16.7	15.0	13.8	15.2	9.9
Phosphate rock 985	9.2	6.5	13.5	10.9	15.2	8.5	23.8	19.2	10.2	11.5	16.4	10.6
Phosphate rock 452	10.1	4.5	11.2	6.9	8.2	5.8	24.3	17.1	9.4	6.8	12.0	11.0
Phosphate rock 1160	11.2	5.6	10.2	7.5	12.7	4.4	24.2	16.4	10.0	10.7	11.1	10.8
Phosphate rock 451	3.7	3.4	7.3	4.9	3.6	2.7	21.9	13.1	7.1	7.9	9.5	7.3
Phosphate rock B-14	8.7	2.4	10.8	5.8	6.2	2.4	21.8	14.8	10.8	9.6	11.0	9.1

was smaller than that from the less acid soil with a pH 5.80. However, in a few treatments, principally those of rocks with a lower percentage of fluorine, there was a relatively larger amount of dry matter produced on the more acid soils.

In order to determine the amount of phosphorus absorbed under the different conditions, the percentage of phosphorus was determined in a nitric acid extract of the residue of a magnesium nitrate fusion of the plant tissue by a volumetric method and the milligrams of phosphorus absorbed calculated. The results are given in Tables 4 and 5. Since the results from the first and second crops were very similar, no analyses were made of the third crop. The results show, as did a comparison of the dry weights, that there is some trend towards an increase in the availability of the phosphate rocks with an increase in soil acidity.

A clearer interpretation of the results can be obtained if the relative amounts of phosphorus absorbed are computed using monocalcium phosphate as the standard in each set of treatments. The results from all series are similar, but only the results for the second crop are given in Table 6, since, as was previously explained, the plants in most jars in this series were apparently using all the phosphorus that was available for growth. The results from the soil with pH 5.80 are not considered in the discussion and they should not be considered typical since the growth results showed the soil to contain considerable available phosphorus.

DISCUSSION AND SUMMARY

The results show very clearly that there is not a close relationship between soil acidity and the increase in the availability of phosphorus in phosphate rocks. For example, with phosphate rock 451 in only one instance of higher acidity, pH 5.80, was there as much phosphorus absorbed as from the soil with a pH of 7.14. Similarly, sample B-14 was an ineffective source of phosphorus, whereas sample 943 supplied sufficient available phosphorus for the plants to make fair growth. Although there is no close relationship between increased soil acidity and availability of phosphorus in phosphate rocks, it appears that there is some tendency for the availability of phosphorus in phosphate rocks to increase with an increase in soil acidity, but even this will not be true in all cases. For example, the results from phosphate rock 451 show a decrease in availability at all degrees of acidity excepting pH 5.80. In addition, all but sample 985 show a decrease in relative availability at pH 4.76.

It appears evident from the results of the growth studies and from the amount of phosphorus absorbed by the plants that it is only in extremely acid soils that the acidity of the soil may increase the relative availability of the phosphorus in phosphate rocks. Furthermore, from the results presented, rock phosphate cannot be recommended indiscriminately as a fertilizer on acid soils similar to those used in these experiments, since the soil acids have not generally increased the amounts of phosphorus absorbed by plants.

TABLE 4.—*Average percentage of phosphorus in Sudan grass grown in soil with nitrogen and potassium and the phosphates and reactions indicated.*

Phosphate	pH 4.33		pH 4.76		pH 5.07		pH 5.80		pH 6.82		pH 7.14	
	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop
None	0.216	0.204	0.200	0.258	0.168	0.125	0.154	0.130	0.186	0.197	0.170	0.209
Monocalcium phosphate	0.190	0.178	0.194	0.267	0.139	0.138	0.148	0.153	0.150	0.190	0.142	0.195
Superphosphate	0.216	0.174	0.200	0.269	0.201	0.147	0.157	0.167	0.152	0.179	0.147	0.189
Tricalcium phosphate	0.172	0.183	0.181	0.232	0.143	0.138	0.160	0.199	0.158	0.172	0.150	0.212
Phosphate rock 943	0.183	0.179	0.180	0.260	0.146	0.144	0.159	0.199	0.173	0.172	0.179	0.240
Phosphate rock 985	0.225	0.186	0.186	0.273	0.130	0.158	0.156	0.167	0.174	0.190	0.163	0.215
Phosphate rock 452	0.200	0.181	0.208	0.260	0.159	0.165	0.135	0.174	0.150	0.178	0.180	0.222
Phosphate rock 1160	0.173	0.170	0.208	0.276	0.158	0.209	0.143	0.180	0.167	0.178	0.167	0.228
Phosphate rock 451	0.206	0.168	0.216	0.273	0.187	0.220	0.134	0.159	0.176	0.203	0.159	0.212
Phosphate rock B-14	0.160	0.168	0.205	0.254	0.184	0.237	0.141	0.169	0.154	0.731	0.140	0.193

TABLE 5.—*Average milligrams of phosphorus absorbed by Sudan grass fertilized with nitrogen and potassium and the phosphates indicated.*

Phosphates	pH 4.33		pH 4.76		pH 5.07		pH 5.80		pH 6.82		pH 7.14	
	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop
None	18.4	5.1	21.6	25.6	16.1	4.4	25.8	18.4	11.0	5.0	6.8	2.7
Monocalcium phosphate	30.0	20.6	28.6	36.3	19.8	23.2	28.3	37.5	19.1	32.9	18.4	44.8
Superphosphate	36.2	18.3	29.4	33.9	31.7	20.6	28.9	40.3	20.2	33.2	20.2	42.7
Tricalcium phosphate	26.6	24.2	28.4	35.3	20.8	19.9	26.2	50.2	23.8	30.9	18.4	41.5
Phosphate rock 943	29.5	19.9	28.1	33.0	19.2	20.5	23.2	48.0	21.6	25.8	18.7	35.7
Phosphate rock 985	34.4	17.2	25.1	36.7	16.0	23.9	26.4	39.6	20.9	19.7	21.9	36.3
Phosphate rock 452	26.3	18.1	29.6	29.2	19.0	14.0	22.1	42.3	16.5	16.7	20.7	26.5
Phosphate rock 1160	23.1	19.0	26.4	28.1	13.4	26.7	19.5	43.5	18.7	18.3	19.3	25.2
Phosphate rock 451	24.0	6.2	28.2	19.9	11.3	8.9	20.5	34.8	16.7	14.4	15.9	19.9
Phosphate rock B-14	20.9	14.4	28.8	27.5	10.7	14.8	19.9	36.7	16.1	18.6	12.8	21.0

TABLE 6.—*Relative percentages of phosphorus absorbed by Sudan grass from phosphates indicated.*

Phosphate	pH 4.33	pH 4.76	pH 5.07	pH 5.80	pH 6.82	pH 7.14
Monocalcium phosphate....	100.0	100.0	100.0	100.0	100.0	100.0
Superphosphate . .	87.4	77.6	86.1	114.6	101.2	95.1
Tricalcium phosphate ...	126.2	90.5	79.7	166.4	92.7	92.3
Phosphate rock 943.	98.0	69.2	85.6	154.9	74.6	78.4
Phosphate rock 985....	80.2	94.5	103.7	111.0	52.7	79.8
Phosphate rock 452	85.1	33.6	51.1	125.0	41.9	56.7
Phosphate rock 1160 ...	92.1	23.4	118.5	126.2	47.7	53.5
Phosphate rock 451	7.4	——	26.6	85.9	33.7	40.9
Phosphate rock B-14 .	61.5	17.8	55.3	95.9	48.7	43.5

The phosphate rocks used in this experiment were selected to determine if the soil acids would increase availability of phosphate rocks in spite of their fluorine content, which has been shown previously[4] to be associated with the availability of phosphorus in phosphate rocks. The results reported also show that the availability of the phosphorus in phosphate rocks is very closely associated with their fluorine content. The results in Table 6 are arranged in the order of decreasing fluorine content of the phosphate rocks, sample 943 having the smallest percentage of fluorine and sample B-14 having the largest. If the results under each degree of acidity are examined, it will be noted that regardless of the degree of acidity, there is a general trend for the availability of the phosphorus in the phosphate rock to decrease as the percentage of fluorine in the rock increases. In appears evident, therefore, that only those phosphate rocks low in fluorine content should be used as direct phosphate fertilizers.

The fact that availability of phosphate rocks seem to be closely associated with the fluorine content of the rock may explain some of the variations which have been found in the availability of rock phosphate by different investigators. An experiment conducted with a phosphate rock having a high percentage of flourine, such as sample B-14, would not show "rock phosphate" to be anywhere near as efficient as a source of phosphorus as phosphate rock 943 or 985.

[4]BARTHOLOMEW, R. P. Fluorine, its effect on plant growth and its relation to the availability of phosphorus in phosphate rocks. Soil Science, 40:203-217. 1935. Private communication from K. D. Jacob.

USE AND FUNCTION OF PEAT IN FOREST NURSERIES[1]

S. A. WILDE AND H. H. HULL[2]

THE beneficial influence of organic matter on soil fertility has been abundantly demonstrated by practical experience and scientific research. Among the manifold functions which organic matter fulfills in the soil, four are of particular importance. It improves the physical properties of the soil, provides nitrogen and other plant food, absorbs mineral salts, and increases the availability of nutrients through its exchange and catalytic effects.

1. IMPORTANCE OF ORGANIC MATTER IN FOREST NURSERY SOILS AND THE PROBLEM OF ITS MAINTENANCE

In no other branch of plant production is a deficiency of organic matter manifested with such sharpness as it is in forest nurseries. Forest trees, especially conifers, develop in their youth on a purely organic layer of forest debris, and thus acquire more or less pronounced saprophytic tendencies. As a rule, forest nurseries are located on sandy soils in order to avoid difficulties with heaving, cultivation, and control of parasites, and most of them have been started either on burned-over areas or on abandoned fields already deficient in organic matter. No crop residues are left in the soil of the nursery because even the root systems of the seedlings are removed. Continuous weeding and cultivation, artificial irrigation, additions of commercial fertilizers, and consequently high biological activity are other conditions promoting a rapid decrease of organic matter in nursery soils. It is evident that under these conditions an adequate supply of organic matter may be maintained only by regular additions to the soil of large quantities of organic materials.

The materials which are usually considered as possible supplements of soil organic matter are manure, commercial organic fertilizers, sawdust, green manuring crops, leaf litter, duff, and peat. However, some of these are very objectionable from the standpoint of nursery practice, and some are acceptable only with certain limitations. Manure of any kind is undesirable because of the danger of diseases. The same is true of commercial organic fertilizers which, in addition, are very expensive. Fresh sawdust exerts a harmful effect upon the seedlings and no safe way has yet been found to counteract its detrimental influence. The green manuring crops, even on a 3-year rotation basis, cannot add to a nursery soil more organic matter than is decomposed during the 3-year period. Thus, the green manuring

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crops may help in maintaining the existing content of organic matter, but they cannot correct a deficiency within a reasonably short time. With certain exceptions, the leaf litter and duff from productive forest stands are very desirable materials, but this type of organic matter is scarce and expensive to gather. Peat is rather cheap, and often readily available, but its suitability for application to nursery soil varies with its origin and composition. Experience during the past 4 years with the use of peat in several state, federal, and private nurseries of the Lake States region has shown that either very satisfactory or entirely unsatisfactory results may be obtained. In order to secure first-hand information on this important subject, an extensive study of the biological, chemical, and colloidal properties of peat materials has been carried out. The results of this study are reported in this paper.

2. IMPORTANCE OF PEAT PROFILE

The reports of stratigraphic studies by Dachnowski (4, 5)[3] present peat as a succession of independent layers composed of widely different plant remains, such as those of mosses, sedges, reeds, wood, and so forth. The importance of the botanical or morphological classification of peat as a basis for chemical investigations was strongly emphasized by Cajander (2) as early as 1913, and the relationship that exists between morphology and chemical properties of peat has been repeatedly demonstrated since that time by Waren (17), Kotilainen (8), and Waksman and Stevens (13, 14, 15, 16).

In view of this, the first step in the selection of peat must be a thorough examination of the peat profile down to the depth of the underlying mineral soil or possible excavation. Two main objects of such an examination are the determination of the nature and extent of the separate layers of peat, and the collection of representative samples for analysis. A general scheme of classification of peat introduced by Dachnowski (3, 4, 5) is of great help in such morphological studies and is reproduced in Table 1. The technic of the profile investigation and of the collection of samples is the same as is adapted to soil studies. In the sampling it is of particular importance to remember that no reliable analytical data can be secured unless the peat samples are taken from homogenous horizons with all the precautions required in the collecting of soil samples, as pointed out by Wilde (19).

3. CHEMICAL CLASSIFICATION OF PEAT VERSUS MORPHOLOGICAL CLASSIFICATION

For a number of years some scientists failed to recognize the importance of the morphological basis in the chemical analyses of peat and thus introduced unfortunate precedents in peat studies. At the same time, other peat investigators fell into error by considering the broad morphological types of peat as chemically homogenous units. The broad, purely botanical classifications of peat often proved to be harmful in practical work as their units included materials of radically different stratigraphic origin and chemical composition. Difficulties of this nature became especially acute in the management of nursery soil, as outlined below.

[3]Figures in parenthesis refer to "Literature Cited", p. 312.

TABLE 1.—*Characteristics of different classes of peat.*

Major classes	Types of peat	Origin	Color, texture, structure
I. Sedimentary peat	Oozy, macerated, or pulpy peat	Aquatic	Olive green, brown to black; coarse to very fine grained, pasty; amorphous, soft, sticky, impervious
	Calcareous sedimentary peat		Gray to grayish brown or cream colored; coarse to finely divided; gritty, crumbly
	Silicious sedimentary peat		Grayish brown to black; fine grained; plastic to friable
Ia. Sedimentary-fibrous peat	Cattail peat, Tule peat, etc.		Dark brown to black; partly stringy fibered sticky to platy; dense, plastic to lumpy
II. Fibrous peat	Reed peat	Marsh	Yellowish, reddish to dark brown; coarse to fine fibered, loamy to powdery; matted to felty porous, brittle
	Sedge peat		Reddish brown to dark brown; coarse to fine fibered, loamy to powdery; matted to felty porous, brittle
	Hypnum moss peat		Yellowish brown to dark brown; fine fibered; loose to firm porous
	Sphagnum moss peat	Bog	Yellowish brown to dark reddish brown; coarse to fine fibered; spongy porous to fluffy
IIa. Woody-fibrous peat	Heath shrub peat		Brown to dark reddish brown; partly fibered, coarse fragmented; firm, lumpy
	Willow-alder peat	Swamp forest	Brown to very dark brown; partly fibered to coarse woody, granular; sticky to loose crumbly
	Bay shrub peat		Brown to blackish brown; partly fibered to coarse woody, granular; compact, sticky to lumpy
III. Woody peat	Coniferous woody peat		Reddish brown to dark brown; coarse woody fragments to granular; loose to firm, lumpy or crumbly
	Mixed woody peat		Brown to dark brown; woody fragments to loamy granular; lumpy to friable
	Deciduous woody peat		Dark brown to black; woody fragments to loamy granular; lumpy to mellow loamy

The vocabulary available to a practical forester for the classification of peat includes but a few terms, such as "moss peat", "sedge peat", "woody peat," and "muck". Each of these types, or, more properly, groups of organic material have been both praised and condemned in various recommendations and instructions on nursery soil management. A survey of the chemical and absorbtive properties of peat revealed that these broad terms have only relative value as far as nursery practice is concerned. In fact, the majority of peat deposits in the Lake States region are not pure types, but differ in the series of superimposed layers and in the character and combination of moss, sedge, read, and wood remains. These remains are derived from numerous species and they occur in various proportions and degrees of decomposition. Consequently, the relation between the chemical composition and morphological properties of peat is too complex and elaborate to be of a direct use in nursery practice. For this reason, an attempt was made in this study to place the classification of peat upon important and easily determinable chemical properties, such as reaction, nitrogen content, and base exchange capacity.

4. REACTION OF PEAT

Fig. 1 presents actual and theoretical frequency curves for the pH values of peat obtained from analyses of about 600 samples from the area of calcareous drift, Dane County, Wisconsin. No data of simultaneous determinations were available in quantity sufficient to construct similar curves for other areas. However, the examination of the departmental records has indicated that similar trend in distribution of pH values of peat may be expected in the entire north-central region. The frequency curves from southern Wisconsin suggest that some fundamental causes are responsible for the occurrence of three distinct groups of peat material, as follows: Alkaline peat having a range of reaction from pH 7.0 to pH 8.0; slightly acid peat of a reaction from about pH 6.0 to pH 7.0; strongly acid peat of a reaction pH 5.5, or less.

In the course of this study it has been found that these three groups of peat—alkaline, slightly acid, and strongly acid—form an important and readily determinable basis for the classification of peat as fertilizing or buffering material. In particular, it was observed that the reaction of peat is intimately correlated with two essential conditions which affect plant growth, namely, development of parasitic fungi and nutrition of the seedlings.

5. INFLUENCE OF PEAT UPON INFECTIOUS DISEASES

Greenhouse and sample plat studies have shown that alkaline peat not only encourages, but also produces damping-off and post damping-off or root-rot diseases, and consequently is entirely unsatisfactory for use in forest nurseries. Slightly acid and neutral peat has a pronounced tendency to encourage the damping-off of coniferous seedlings, but it initiated the disease in only one out of seven cases. It is not desirable in nurseries raising coniferous stock, but may be

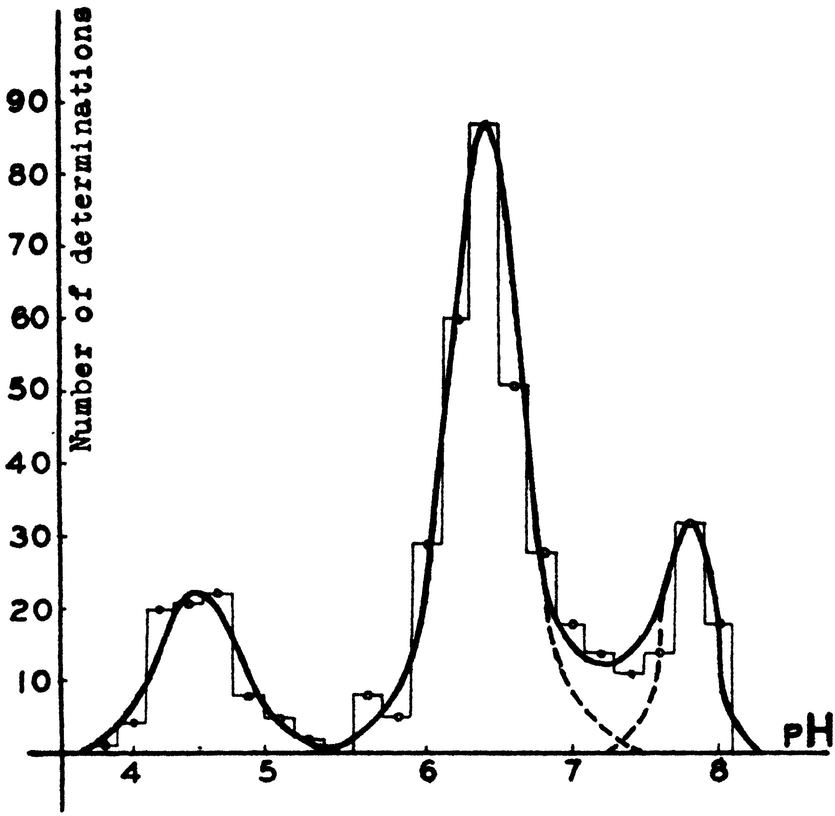

FIG. 1.—Actual and theoretical frequency curves for the pH values of peat from southern Wisconsin.

satisfactory in nurseries raising deciduous trees or transplants. Pot tests and trials on small areas of the nursery should be made before peat of this reaction is applied on a large scale. Not a single case has been observed in which strongly acid peat has produced or even encouraged the damping-off of the seedlings. No cases of root-rot infection were recorded where acid peat was applied. In many instances the strongly acid peat decreased the percentage of damped-off seedlings.

The results of an experiment with infested soil and applications of peat of different reactions are summarized in Fig. 2. Fifty-two half-gallon glazed jars were filled with 2,500 grams of sandy soil infested with damping-off fungi. Eight jars were filled with soil only. Each of the remaining jars received 100 grams of air-dry peat. Eleven peats were used and each treatment was replicated four times. Twenty-five seeds of Norway pine (*Pinus resinosa*) were planted in each pot and four months later the surviving seedlings were counted. Seed of a high percentage of germination was used and no discount for failure of germination was made. Observations in forest nurseries,

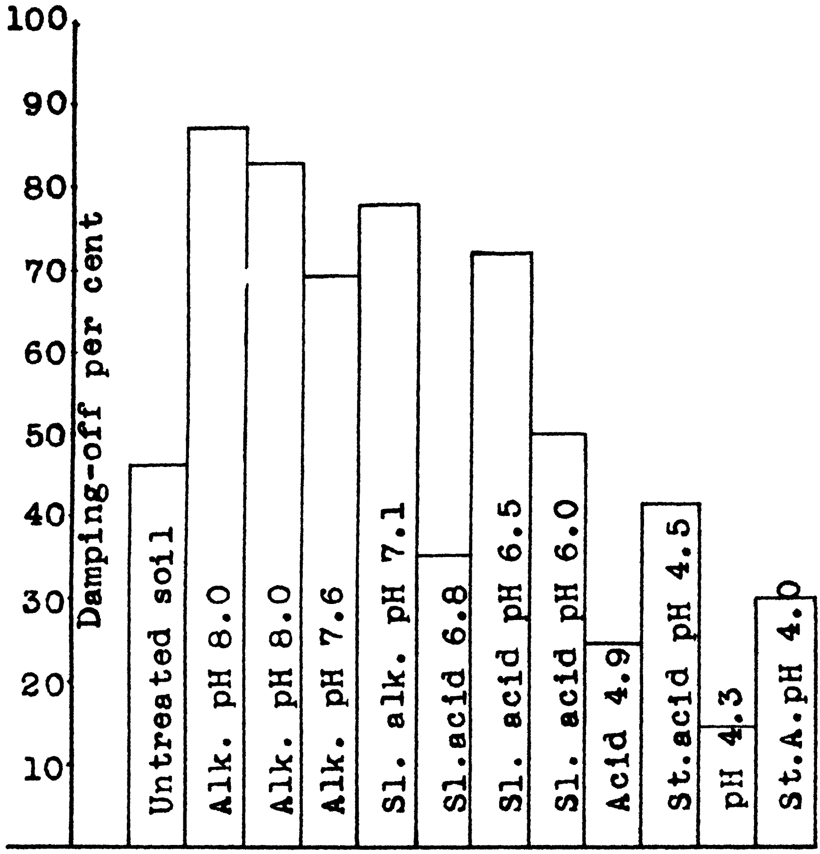

FIG. 2.—Effect of application of peat of different pH value to soil infested with damping-off fungi.

on sample plats, and in several other greenhouse tests confirmed the results of this experiment.

6. PEAT AS A SOURCE OF ESSENTIAL NUTRIENTS

The results of the total analyses of the peats used in this study were compared with those reported by Zailer and Wilk (21), Minssen (9), Birk (1), Dachnowski (3), Waksman and Stevens (13, 16), Whitson (18), and Feustel and Byers (6). The minimum, maximum, and average values obtained in this way are given in Table 2. A few of the extreme values reported in isolated instances were disregarded as doubtful. A considerable part of the data was taken from the summary reported and interpreted by Dachnowski (3). Only types of peat which are likely to be important in nursery practice were considered. The study was further limited to highly organic materials containing at most 8% of mineral ingredients.

Bearing in mind the high rate of mineralization of organic matter in nursery soil, it is reasonable to expect that the constituents of the

peat material will be released as available nutrients within a period of several years. Therefore, the average values of Table 2 enable one to estimate sufficiently accurately the value of peat as a possible source of fertilizing substance. While the general average is derived from a combination of widely different materials, it is of a considerable significance because the majority of deposits are a mixture of moss, sedge, and wood remains.

A comparison of the data in Table 2 with the nutrient requirements of seedlings reveals that three of the elements important in nutrition, namely, calcium, iron, and sulfur, occur in all types of peat in quantities exceeding the desirable minimum and, hence, are not of decisive importance in the selection of peat material.

A little consideration will show that the content of phosphoric acid and potash is of minor significance in the selection of peat. Assuming a maximum content of 0.15% of each constituent and a fairly high application of 10 tons of peat per acre, the total quantity of either P_2O_5 or K_2O added amounts to only 30 pounds per acre. This is equivalent to 150 pounds of 20% superphosphate and 60 pounds of 50% muriate of potash, which would be worth, in all, about $7.00. This sum will seldom justify any extra expense in securing peat of a higher content of total potash and phosphorus.

When considering the properties of peat as a composting medium, its content of readily available phosphoric acid and potash are of greater importance than the total content of these constituents. Fig. 3 presents the mean values and theoretical curves of available P_2O_5 and K_2O found in peats of different reaction. This diagram is based on analysis of nearly 1,000 samples from the Wisconsin area. The majority of analyses have been made by the Wisconsin State Soils Laboratory. The availability curves obtained in this study indicate that the strongly acid peat near pH 4.0 equals or exceeds peat of any reaction below pH 6.5 in its content of available P_2O_5 and K_2O. This coincides well with the requirements of nursery practice since peat of strongly acid reaction is preferable.

Although the total nitrogen in the peat is not wholly available to the plants, it has an important bearing on the quantity of available nitrogen released in the form of ammonia and nitrates, as shown by Russell (12). Studies in Wisconsin have established quite definitely that 0.1% of total nitrogen is the lower limit of nitrogen content for a productive nursery soil.

The practical significance of variation in the content of total nitrogen of peat is easily demonstrated by a concrete example. Suppose the nitrogen content in a nursery soil is 0.08% and the nitrogen content of the peat is 2.5%. This means that in order to correct the deficiency of 0.02% in the surface 6¾-inch layer of soil and thus raise the nitrogen content of the soil to 0.1%, it is necessary to apply 16,000 pounds ($2,000,000 \times 0.02 \div 2.5$) or 8 tons of peat per acre on the dry basis. In order to correct the same deficiency with peat having only 1% of total nitrogen, it will be necessary to apply 40,000 pounds or 20 tons per acre of raw material. Thus, the difference in the total nitrogen content may easily double the expense of fertilization.

TABLE 2.—*Total analysis of moss, sedge, and woody types of peat.*

Type of peat	Variation and average	Organic matter, %	Ash, %	SiO_2 and insolubles, %	N, %	P_2O_5, %	K_2O, %	CaO, %	$Fe_2O_3+Al_2O_3$, %	SO_3, %
Bog-moss peat		99.36	0.64	1.69	0.63	0.03	0.02	0.08	0.07	0.08
(Sphagnum)	Range	96.08	3 92	0.18	1.38	0.08	0.12	1.78	0.47	0.44
Weighted av.		97 80	2 20	0.70	0.92	0 04	0.06	0.20	0.25	0 23
Brown-moss peat		96 68	3.32	0.26	1.98	0 05	0.05	0.52	0.32	0.26
(Hypnum)	Range	92.39	7.61	2.73	2.25	0.08	0.12	1.42	0.70	0.43
Weighted av		94.50	5.50	1.50	2.09	0 06	0.08	1.00	0.60	0.34
Sedge peat		96.49	2.83	0.28	1 32	0.04	0.03	0.50	0.40	0.28
(Carex)	Range	93.88	6.12	1.79	4.20	0.16	0.27	2.90	1.47	0.81
Weighted av.		95.30	4.70	0.90	2.91	0.10	0.15	1 95	1.00	0.43
Woody peat		98.40	1.60	0.40	0.86	0.05	0.03	0.40	0.43	0.20
(Deciduous and coniferous)	Range	90.70	9.30	3.90	3.27	0 10	0.27	7.90	4.03	2 19
Weighted av.		94.50	5.50	1.70	2.05	0.11	0.12	1.41	1.37	0.92
General approximate av.		95.00	5.00	1.20	2.00	0.08	0.10	1.15	0.80	0.50

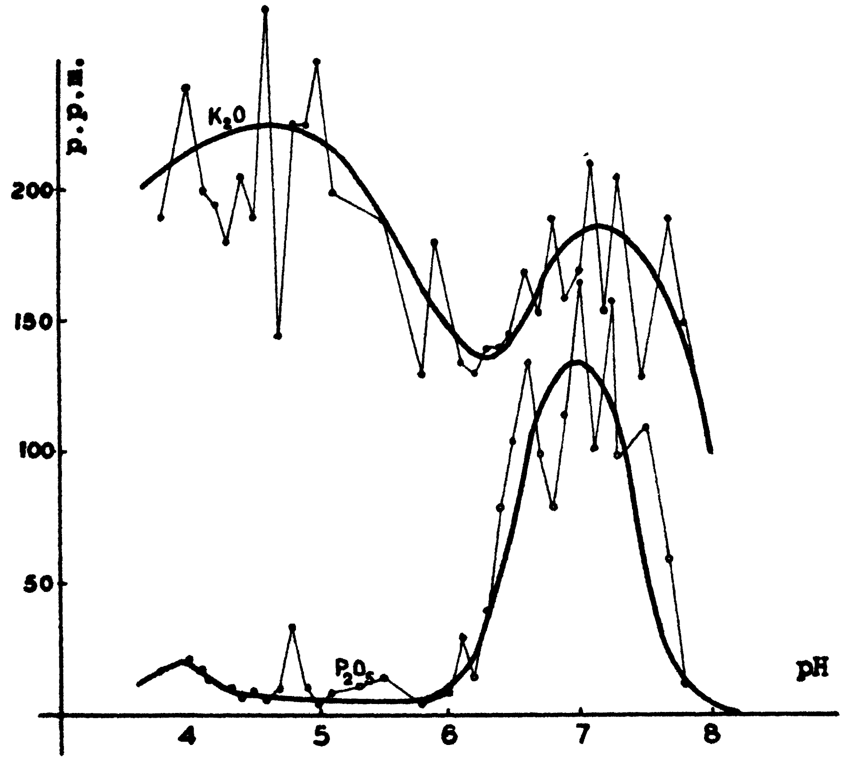

FIG. 3.—Actual and theoretical curves for the available phosphoric acid and potash of peat of different pH values.

The results of analyses (Tables 2 and 3) indicate that it is reasonable to consider peat having 2% or more of total nitrogen as a very satisfactory source of nitrogen. Peat having less than 1% of total nitrogen is of low value as far as its nitrogen content is concerned.

7. ABSORBING AND BUFFERING PROPERTIES OF PEAT

If fertilizers are applied to a soil having an insufficient content of mineral colloids or organic matter, they may be soon washed out by rains or artificial watering. In times of drouth the moisture content of soils deficient in colloidal material rapidly decreases through evaporation. As a result of this, fertilizers are carried upward and accumulate at the soil surface. In this way, the concentration of fertilizer salts may increase from about 500 p.p.m. to several thousand p.p.m. in the surface inch. This high concentration is responsible for the chemical injury or "burning" of the roots of the seedlings, according to Wilde (20).

The absorbing properties of soils are influenced by numerous factors of physical, chemical, and biological nature. Among these, the effect of the base exchange fraction of soil colloids is of particular importance in regard to the function of peat in nursery soils.

When fertilizers, such as ammonium sulfate and potassium chloride, are added to the soils, together with acid peat of high base exchange capacity, their basic ions are exchanged with hydrogen of the peat according to the following equations:

$$KCl + H.\ Peat \longrightarrow K.\ Peat + HCl$$

$$(NH_4)_2 SO_4 + 2\ H.\ Peat \longrightarrow 2\ NH_4.\ Peat + H_2SO_4$$

In this manner, the addition of peat preserves the valuable part of fertilizers from leaching and releases the acid radicals which combine with the hydrogen liberated from the peat and may be eventually washed out in form of acids.

Moreover, the addition of exchange material in the form of acid peat may increase the availability of ferric iron, tri-calcium phosphates, and perhaps some other nutrients present in soils as difficultly soluble compounds as shown by Gedroiz (7), Oden (10), and Prianishnikoff (11).

Analyses of about 30 forest nursery soils of the Lake States region showed that the exchange capacity of about 90% of these soils did not exceed 7 M.E. per 100 grams of soil, whereas the satisfactory capacity may be estimated as 10 M.E. per 100 grams. This common deficiency of exchange material in nursery soils is due to their mode of origin and the requirements of nursery practice. The "level, stone-free, sandy loam soils", so persistently recommended for forest nurseries by the silvicultural textbooks, are rarely found in nature. Sandy loam soils are usually of morainic, less commonly of residual, and seldom of outwash origin. Consequently, they are either stony, gravelly, or of rolling topography, and, hence, are unsuitable for nursery practice. On the other hand, stone-free and level soils are outwash soils, which are predominantly either sands or silt loams. Since the heavy silt loam soils are undesirable because of heaving, difficulties in control of parasites, and cultivation, the problem of base exchange deficiency will continue to be one of the most acute in the management of nursery soils.

There are few alternatives among the possibilities of increasing the exchange capacity of nursery soils. In some rather exceptional cases, this may be accomplished by the addition of mineral colloids, or clay. However, non-calcareous and otherwise suitable clay deposits or clay-loam subsoils are scarce and the exchange capacity of these materials does not exceed 40 M.E. per 100 grams of soil. On the other hand, peat is widely distributed and its exchange capacity may be as high as 150 M.E. per 100 grams.

The significance of base exchange capacity of peat applied to the nursery soil is evident from the following example. Suppose that the exchange capacity of a nursery soil is 7 M.E., that 10 M.E. is the desirable capacity, and that the capacity of the available peat is 100 M.E. per 100 grams. In order to correct the deficiency of 3 M.E. in 2,000,000 pounds of soil, the following amount of peat must be applied:

$$2{,}000{,}000 \times 3 \div 100 \text{ or } 60{,}000 \text{ pounds or } 30 \text{ tons of peat.}$$

In case the available peat has an exchange capacity of only 50 M.E.

per 100 grams, it is necessary to double this amount in order to correct the same deficiency.

Table 3 gives the averages of data for the reaction, total nitrogen content, and exchange properties of 24 representative peat materials. These have been used on a large scale in different forest nurseries for direct application and for composting, as well as in the experimental work in the greenhouse and on sample plats. Consequently, these materials were repeatedly examined and analyzed. The data presented in Table 3, as well as many other analyses of peat from the Lake States region, suggest that peat desirable for use as a buffering material must have an exchange capacity of at least 80 M.E. per 100 grams. A base exchange capacity of 100 M.E. is very satisfactory and is likely to occur in a large percentage of peat deposits.

TABLE 3. - *Average data of the reaction, total nitrogen, base exchange capacity, and replaceable bases of peat used in forest nurseries or in experimental work.*

No.*	Type of peat	Reaction pH	Total N %	Base exchange, M. E. per 100 grams	Replaceable Ca, M. E. per 100 grams	Replaceable Mg, M. E. per 100 grams
1	Woody	4.9	1.73	93.3	14.5	5.4
2	Sedge-Moss	5.5	2.10	98.6	43.8	6.8
3	Sedge-Moss	4.7	2.11	86.5	17.9	6.3
4	Moss	4.7	0.96	66.5	9.6	4.0
5	Sedge-Moss	4.3	2.19	127.7	12.8	2.9
6	Sedge-Moss	4.7	2.23	112.2	17.1	3.8
7	Sedge	6.0	1.69	89.3	52.3	8.7
8	Sedge-Moss	4.5	2.07	83.3	16.0	3.5
9	Moss	3.7	0.69	67.1	2.3	0.4
10	Sedge-Moss	4.7	1.50	76.0	7.0	2.0
11	Sedge	4.5	2.16	129.9	16.6	3.4
12	Sedge	4.3	1.82	81.5	5.9	1.8
13	Sedge-Moss	4.9	1.52	62.7	7.8	5.6
14	Sedge-Moss	4.5	2.19	143.0	18.2	4.0
15	Sedge	5.0	1.71	89.7	11.4	3.7
16	Sedge-Moss	4.2	1.63	146.0	15.6	2.2
17	Sedge-Moss	5.0	2.62	119.0	43.2	5.6
18	Woody	6.7	1.55	144.2	117.0	21.7
19	Sedge-Moss	4.3	1.67	97.4	11.2	3.4
20	Sedge-Moss	4.2	1.73	102.7	9.9	4.4
21	Moss	4.0	0.72	62.2	5.1	0.2
22	Moss	3.9	0.66	58.3	3.1	0.2
23	Moss	4.3	0.66	103.0	7.0	1.3
24	Moss	4.0	0.64	122.5	4.7	0.4

*Place of occurrence and use: 1. Trout L., Wis., No. State Ny., 1932, 1933. 2. Same, 1933, 1934. 3. Tomahawk, Wis. No. State Ny., 1935, 1936. 4. Trout L. No. State Ny., 1936. 5. City Point, Wis., Cent. State Ny. and Nepco Ny., 1934, 1935, 1936. 6. Same. 7. Wisconsin Rapids, Nepco Ny., 1935. 8. Gordon, Wis., State transplant Ny., 1933 to 1935, and ECW Ny., 1936. 9. McNaughton, Wis., sample plats in State forestry camp, 1933. 10. McNaughton, State transplant area, 1935. 11. Vicinity of Madison, 1932, U. W. greenhouse. 12. Waukesha, Wis., U. W. greenhouse since 1933. 13. Jefferson Co., Wis., U. W. greenhouse since 1934. 14. Dane Co., Wis. Same. 15. Watersmeet, Mich., U. S. F. S. Ny., 1935. 16. East Tawas, Mich., U. S. F. S. Ny., 1934. 17. Wellstone, Mich., U. S. F. S. Ny., 1936. 18. Manistique, Mich. U. S. F. S. Ny., 1934, 1935. 19. Cass L., Minn., U. S. F. S. Ny, since 1934. 20. Eveleth, Minn., U. S. F. S. Ny., 1936. 21. Imported from Germany; U. W. greenhouse and sample plats. 22. Same. 23. Imported from Sweden, U. W. greenhouse. 24. Same.

8. FERTILIZING EFFECTS OF PEAT UPON FOREST SEEDLINGS

In order to obtain general information on the fertilizing value of peat for forest seedlings a number of peat materials were investigated

in the greenhouse. The various peats were mixed with different soils at the rate of 1 part by volume of peat to 3 parts of soil. The mixture was placed in half-gallon glazed jars and 30 seeds of spruce or pine species were planted in each jar. Each treatment was duplicated. After 2 years, the seedlings were removed, dried in the oven at 60° C, weighed, and the average weights calculated as arithmetic means.

The results of the experiments showed that all peats, when added to quartz sand, produced abnormally small, under-nourished seedlings. The minimum average weight of 55 mgm per 2-year-old Norway spruce seedling was produced by Sphagnum moss peat, whereas the maximum weight of 205 mgm was produced by sedge peat. The productivity of woody and other varieties of peat ranged in between these two extremes. The average weight of the 2-year-old spruce seedling grown simultaneously with hardwood-hemlock duff was 859 mgm (Fig. 4).

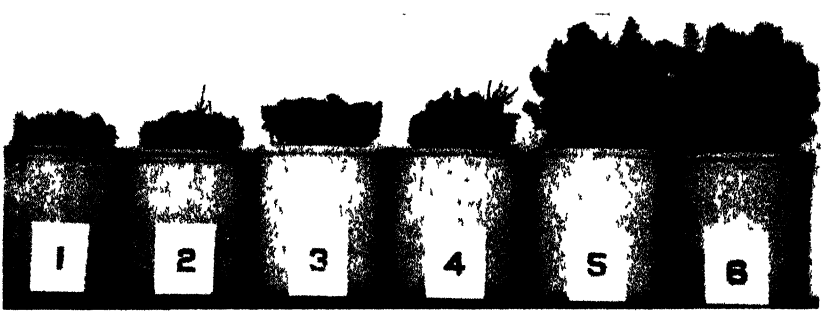

FIG. 4.—Growth of 2-year-old Norway spruce seedlings on quartz sand treated with different organic materials 1 and 2, 4% of sphagnum moss peat low in nutrients. 3 and 4, 4% of Carex sedge peat "high" in nutrients. 5 and 6, 4% of hardwood hemlock duff.

An entirely different picture of the effect of peat on seedlings was observed when peat was applied to soils containing some amount of nutrients, mainly phosphorus and potash, even though these nutrients might not have been in readily available form.

During the last 4 years Messrs. P. Smith, W. H. Brener, and B. George of the Wisconsin Conservation Department have obtained a remarkable increase in growth of seedlings and green manuring crops through the application of acid sedge-moss peat without other fertilizing materials. These results were confined to sandy soils derived from granitic rocks (Plainfield and Vilas light sandy loams), and included Norway spruce, white pine, black locust, and buckwheat. This beneficial effect of peat upon the growth of seedlings must be attributed to a complex of factors, such as the buffering properties, the availability of peat nitrogen in the presence of phosphorus and potash, and the increased availability of other nutrients, particularly iron.

An especially striking example of this more or less indirect fertilizing effect of peat was observed in greenhouse experiments with podzol hardpan from the U. S. Forest Service Nursery at Manistique

on the northern peninsula of Michigan. In this nursery the firmly cemented hardpan layer was exposed in small patches as a result of grading operations and failed to produce a satisfactory growth of seedlings. In the greenhouse, the hardpan was pulverized, treated with mineral fertilizers and peat, and seeded to Norway pine. After a 2-year period the following results were recorded: The average weight of the seedlings grown on untreated soil was 171 mgm; the average weight of seedlings on the soil treated with 700 pounds per acre of a 6–9–14 fertilizer was 520 mgm; the average weight of the seedlings grown on soil with the same fertilizer plus 4% of acid sedge-moss peat was 915 mgm (Fig. 5).

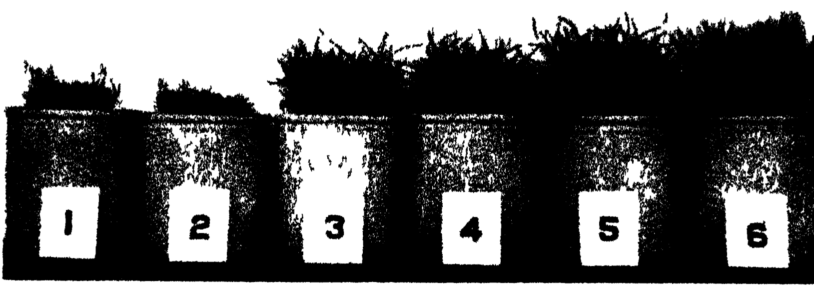

FIG. 5.—Growth of 2-year-old Norway pine seedlings on podzol hardpan soil treated with mineral fertilizers and peat. 1 and 2, Check. 3 and 4, 700 lbs. of a 6–9–14 fertilizer. 5 and 6, 700 lbs. of a 6–9–14 fertilizer plus 4% of acid sedge-moss peat.

The exact nature of the direct and indirect fertilizing effects of peat is under further investigation.

9. PHYSICAL PROPERTIES OF PEAT

The mechanical devices of a modern forest nursery make possible the use of peats having a very wide range of physical properties. Shredding machines, new methods of composting, artificial irrigation, and improvements in the distribution of organic matter in soil enable one to develop a desirable state of soil moisture and aeration with almost any available material. Consequently, among the numerous physical properties of peat only one seems to be of decisive importance in modern nursery practice, namely, the tendency of certain, highly dispersed types of peat to cement the soil. The crust thus formed cracks upon drying and may lead to the breakage of the seedling roots. This condition becomes especially destructive when the peat is not worked thoroughly and deeply into the soil. Macerated peats, colloidal peats, mucks, and some woody peats are likely to have this injurious cementing ability in various degrees (Table 1). On the other hand, the varieties of fibrous peats generally tend to develop a favorable soil texture.

When peat of a high water-holding capacity is applied as a top dressing, it absorbs the entire precipitation and the seedlings or

transplants are liable to suffer from drought. Since top dressing is an undesirable practice in forest nurseries in many other respects, no consideration is given to this condition. Experiments have shown that peat of a high hygroscopicity will not deprive the seedlings of available water and create a condition of physiological drought providing it is thoroughly distributed in the entire 6- to 8-inch layer of soil

SUMMARY

The importance of morphological and stratigraphic studies in the selection of peat for use in forest nurseries is emphasized, but attention is called to the wide chemical variation of peat belonging to the same morphological type.

Three chemical properties of decisive importance, namely, reaction, base exchange capacity, and total nitrogen content, are advanced as a basis for the selection of peat as a fertilizing and buffering material.

Peat having a reaction of pH 5.5, or less, was found to be most desirable for the great majority of nurseries, particularly for those raising coniferous stock. Peat of a reaction from pH 6.0 to 7.0 may be satisfactory for hardwood or transplant nurseries, but is undesirable for nurseries raising coniferous seedlings because of the danger of damping-off and other infectious diseases. Peat having a reaction higher than pH 7.0 is unsatisfactory because of the danger of diseases and direct toxicity of carbonates.

Peat having a total nitrogen content of 2% or more is considered as a very satisfactory source of nitrogen, whereas peat having a total nitrogen content of less than 1% is a low source of nitrogen

A base exchange capacity of peat of 80 M.E. per 100 grams appears to be the allowable minimum, while a capacity of 100 M.E. is quite satisfactory.

The direct and indirect beneficial effects of peat upon forest seedlings were demonstrated. The use of colloidal or macerated peat in forest nurseries is inadvisable, as such materials tend to cement the soil particles.

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INFLUENCE OF CERTAIN OAT VARIETIES ON THEIR F_1 PROGENY[1]

F. A. COFFMAN AND HARLAND STEVENS[2]

THE ability of a parent to transmit uniformly a desirable character to its offspring has been recognized and highly prized by breeders of livestock for generations. Plant breeders, however, have given comparatively scant attention either to the existence of this phenomenon in plants or to its possibilities in plant improvement.

Among plant scientists, corn breeders have far outdistanced all others in recognizing and making use of the fact that certain strains of their crop have the ability to induce increased vigor in hybrid progeny. Kiesselbach (8)[3], Richey (11), Richey and Mayer (12), Nilsson-Leissner (10), Jorgenson and Brewbaker (7), Jenkins (5), Richey and Sprague (13), Lindstrom (9), and Jenkins (6) present data in this connection on studies in corn, but except for data published by Coffman and Wiebe (3), and Coffman and Davis (1, 2) on oats, and a paper by Engledow and Pal (4) on wheat, which touch upon this subject, no reports of studies of prepotent influence in small grain seem available.

The ability of a parent to impress its progeny with certain of its characters is frequently spoken of as prepotency. Prepotency usually is considered as being due to the presence of dominant genes in the homozygous condition. Study of the influence of certain oat varieties on their F_1 progeny was prompted by the observation that some varieties usually produce excellent progeny whenever crossed, whereas others produce little of value.

Studies of the vigor of plants of F_1 hybrids and of their parental lines have been conducted for several years at Aberdeen, Idaho. Since the publication of previous reports additional data have accumulated and are presented herewith.

EXPERIMENTAL DATA

Oats are grown at Aberdeen, Idaho, under irrigated conditions. Data were obtained on plants grown under irrigated conditions at Aberdeen in 1927, 1930, 1931, 1932, 1933, and 1934. Experimental procedures were the same in all years. The seed was space planted at 1-foot intervals in rows 1 foot apart. The hybrids were grown adjacent to their respective parental lines similarly spaced. Wherever blanks occurred, a plant of the Richland variety was grown as a "space filler".

Oats are recognized as especially difficult to hybridize, consequently comparisons of F_1 plants with their parents are limited by the difficulty

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[2]Associate Agronomist and Assistant Agronomist, respectively. The writers express appreciation to C. G. Colcord, Scientific Aide, who made the statistical analysis of the data.

[3]Numbers in parentheses refer to "Literature Cited", p. 323.

of making a sufficient number of crosses for studies of this nature. However, a number of crosses have been made with each of several varieties.

Although, admittedly, variations in size occur among hybrids from identical parents, comparisons tend to show that variation among hybrid individuals resembles closely variation among individuals within their respective parental lines. Data on the following plant characters in parent and F_1 hybrid are presented: (a) Height of plant, (b) culms per plant, and (c) yield of grain.

INFLUENCE OF HEIGHT OF PLANT

As measured by their hybrids, different oat varieties differ widely. Some apparently strongly influence the size characters of their progeny, whereas others largely, if not wholly, lack this ability. Also, a variety may influence one character in its F_1 progeny rather uniformly yet appear to have little or no influence on some other character. In Table 1, data are presented on F_1 plants of crosses of Markton, Black Mesdag, Nortex, Richland, Victoria, and Bond. Figs. 1 to 3 show certain of these data graphically.

Fig. 1 shows that Markton, a rather tall variety, crossed on strains shorter than Markton usually produced F_1 individuals more nearly approaching Markton in height. When crossed with strains approximately equal to Markton in height, indications of hybrid vigor frequently were observed and in several crosses increases above the height of Markton resulted. The difference in height between Markton and its F_1 hybrid plants was not statistically significant, but the hybrids were very significantly taller than the varieties crossed with Markton ($P = 0.04$).

The height of the F_1 hybrids of Black Mesdag bore the same relation to their parents as the hybrids of Markton bore to Markton. The F_1 hybrids of both varieties usually more nearly approximated these parents in height than they did the varieties crossed with them.

Hybrids of Richland and Nortex indicated that these varieties had little influence on plant height in their progeny. The F_1 hybrids of Nortex and Richland were significantly taller than these varieties and more often approximated the other parents to the cross.

Richland, when crossed with shorter varieties, produced F_1 plants usually approximating Richland in height; therefore, they may be considered as having contributed no factors for height not carried by the Richland variety. When Richland was crossed with varieties taller than itself the height of the F_1 usually approximated or was increased beyond that of the taller parent.

Nortex was crossed with only four varieties, all taller than itself, and all F_1 hybrids exceeded Nortex in height. The F_1 plants either exceeded or approached the taller parent in all cases. Consequently, the data available on Nortex crosses indicate that the hybrid was significantly taller than Nortex ($P = 0.03$) but not significantly taller than the other parent.

The F_1 hybrids of Victoria closely approximated Victoria in height ($P = 0.94$) and were markedly taller than their other parents

TABLE 1.—*Comparative measurements of parent and F_1 progeny oat plants of crosses made with the check or designated varieties.*

Cross No.	Other parent to cross	Number of crosses	Plant height, cm			Culms, number			Yield grain, grams		
			Check variety	Other parent	F_1	Check variety	Other parent	F_1	Check variety	Other parent	F_1
	Markton										
X2712	Richland (♀)	4	89.2	67.3	88.0	14.0	9.8	12.8	22.7	8.5	27.0
X2713	Richland (♀)	1	90.8	67.6	90.0	19.0	10.8	11.0	28.7	12.6	26.0
X2714	Fulghum (♀)	2	92.5	73.0	83.5	17.7	19.7	18.0	26.2	11.8	19.0
X2738	Edkin (♀)	1	93.8	81.5	82.0	21.5	16.0	12.0	32.3	21.5	17.0
X2737	Iogold (♂)	2	97.4	94.2	96.0	17.2	17.8	13.0	28.4	22.0	23.5
X2753	Black Mesdag (♂)	2	92.7	95.0	92.0	16.3	14.3	9.0	28.3	14.3	14.5
X2754	Cornellian (♀)	2	90.8	97.0	94.0	13.6	10.0	11.5	18.6	16.8	13.0
X3323	Edkin Sel. (♀)	1	113.0	109.0	118.0	21.0	23.0	19.0	38.8	42.5	39.4
X3328	Aurora (♀)	1	123.0	120.0	131.0	24.0	13.0	18.0	45.6	26.0	38.9
	Black Mesdag										
X2755	Fulghum Fatuoid (♀)	1	98.3	66.7	85.0	10.0	28.8	17.0	24.7	11.0	18.0
X271	Burt Fatuoid (♀)	1	105.0	79.5	100.0	12.3	12.2	13.0	27.3	12.8	25.0
X2753	Markton (♀)	2	95.0	92.7	92.0	14.3	16.3	9.0	14.3	28.3	14.5
X2742	North Finnish (♀)	5	94.4	96.8	100.4	11.8	13.0	13.4	14.2	18.2	22.0
X2722	Monarch (♂)	1	100.7	97.3	101.0	14.0	19.0	16.0	21.0	21.3	24.0
X275	Monarch (♀)	3	100.0	98.7	105.0	10.6	13.2	11.3	27.0	21.2	31.7
X2717	Monarch (♀)	1	101.5	99.6	102.0	18.5	10.6	15.0	18.5	20.2	26.0
	Bond										
X323	Fulghum (♂)	2	79.5	79.5	90.5	22.0	37.5	18.0	33.0	33.5	31.9
XA1132	Fulghum (♀)	4	101.0	87.0	99.5	16.0	26.3	21.0	26.6	20.4	26.6
X325	Carleton (♂)	2	84.5	90.0	91.0	16.0	30.5	21.0	22.4	54.5	37.7
XA1131	Iowa 444 (♀)	3	99.7	110.0	105.0	15.3	18.7	15.0	24.1	33.7	27.4
XS1121b	Lee (♀)	2	96.5	120.0	102.5	17.0	21.5	16.5	23.1	40.6	26.8
XS1121a	Lee (♀)	3	98.3	121.7	112.0	15.0	21.7	16.0	21.5	33.6	26.3
XS1122a	Alber (♂)	1	92.0	112.0	91.0	13.0	32.0	23.0	14.2	24.2	26.2

	Richland										
X3418	Sel. 3128-1 (♂)	3	78.0	78.7	85.9	20.3	22.0	17.7	20.4	24.8	25.6
X2710	Fulghum (♂)	4	69.3	71.4	80.8	13.7	16.0	18.8	16.5	9.8	22.3
X342	Sel. 779-4 (♂)	1	92.7	81.3	91.4	31.0	13.0	35.0	21.0	16.5	29.8
X341	Sel. 779-4 (♀)	1	91.4	83.8	88.9	23.0	26.0	22.0	21.0	16.5	12.5
X3417	Sel. 3128-1 (♀)	1	94.0	83.8	83.8	20.0	24.0	22.0	20.4	24.8	28.4
X2712	Markton (♂)	4	67.3	89.2	88.0	9.8	14.0	12.8	8.5	22.7	27.0
X2713	Markton (♂)	1	67.6	90.8	90.0	10.8	19.0	11.0	12.6	28.7	26.0
XS1102	Sunrise (♂)	3	101.0	101.7	114.3	19.7	20.3	15.3	28.6	14.3	22.9
	Victoria										
X3024	Kanota (♀)	4	105.8	97.0	102.8	18.5	19.8	25.3	36.6	15.7	34.4
X3016	Trojan (♀)	2	108.3	97.7	107.7	20.3	16.3	18.3	36.2	20.4	33.5
X3012	Nortex (♀)	3	107.3	98.3	102.3	20.0	24.3	24.7	41.8	26.4	33.6
X3052	Glen Innes (♀)	4	106.3	117.0	116.0	20.3	14.5	22.0	36.9	19.3	36.1
	Nortex										
XS1127	Berger (♂)	1	90.0	103.0	104.0	42.0	47.0	39.0	24.4	13.6	32.0
X3332	Alber (♂)	3	92.3	106.0	111.3	25.3	36.0	32.7	24.9	12.5	34.9
X3012	Victoria (♂)	3	98.3	107.3	102.3	24.3	20.0	24.7	26.4	41.8	33.6
XA1130	Country Common (♂)	2	86.5	112.0	101.5	39.5	24.0	31.0	19.9	9.2	34.9

(P = 0.14). This indicated Victoria strongly influenced plant height in its F_1 hybrids.

Plant height was studied in seven crosses of Bond with varieties usually taller than Bond. In seven crosses three of the F_1 hybrids more closely approached the height of Bond than that of the other parent. On the whole, however, the hybrids were significantly taller than the Bond parent (P = 0.04). They more nearly approached the other parent of the cross.

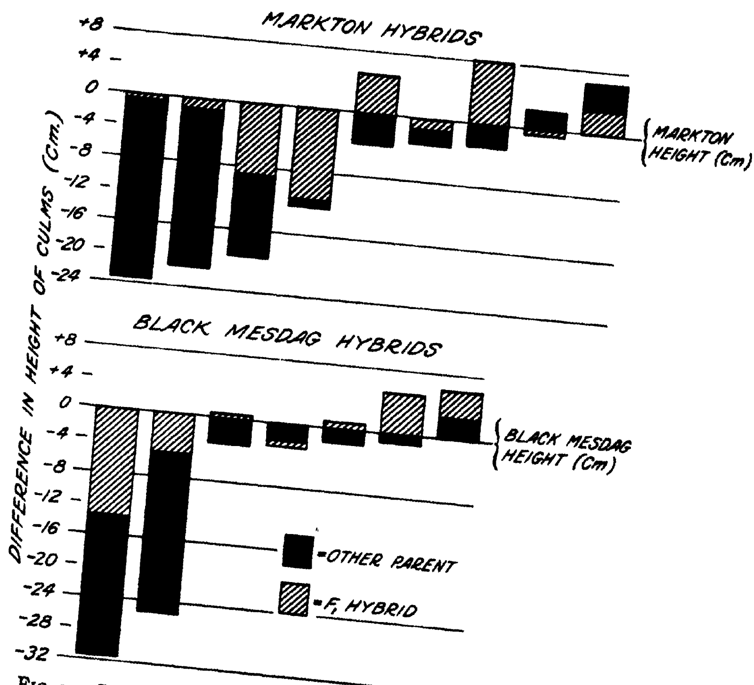

FIG. 1.—Comparison of height of plant in parents and F_1 plants of Markton and Black Mesdag oat crosses.

INFLUENCE ON CULMS PER PLANT

It has previously been reported (3) that F_1 plants frequently have fewer tillers than plants of their respective parental lines. Additional evidence for this belief is presented in Table 1 and is shown graphically in Fig. 2. In eight of nine crosses of Markton the F_1 plants bore fewer culms than Markton and in four crosses fewer culms than either parent. The P value of the difference between Markton and its F_1 hybrids was less than 0.01. Consequently, the absence of any influence of Markton on culms per plant in its F_1 progeny seems evident. Although Markton usually produces numerous tillers as compared with other spring-sown oats, it is not an especially heavy stooling variety. The number of culms per plant in parent and F_1

progeny in most other varieties show slight indications of prepotency. As many F_1 progeny of Nortex resembled one parent as the other. Indications of hybrid vigor were observed among some crosses of Victoria, but such indications were slight among the F_1 crosses of Nortex.

Among the F_1 hybrids of Black Mesdag and Richland six of seven of the former and five of eight of the latter more nearly approximated these parents in culms per plant; yet no statistically significant difference existed between culms per plant of the F_1 plants of these crosses and those of either parent to the cross.

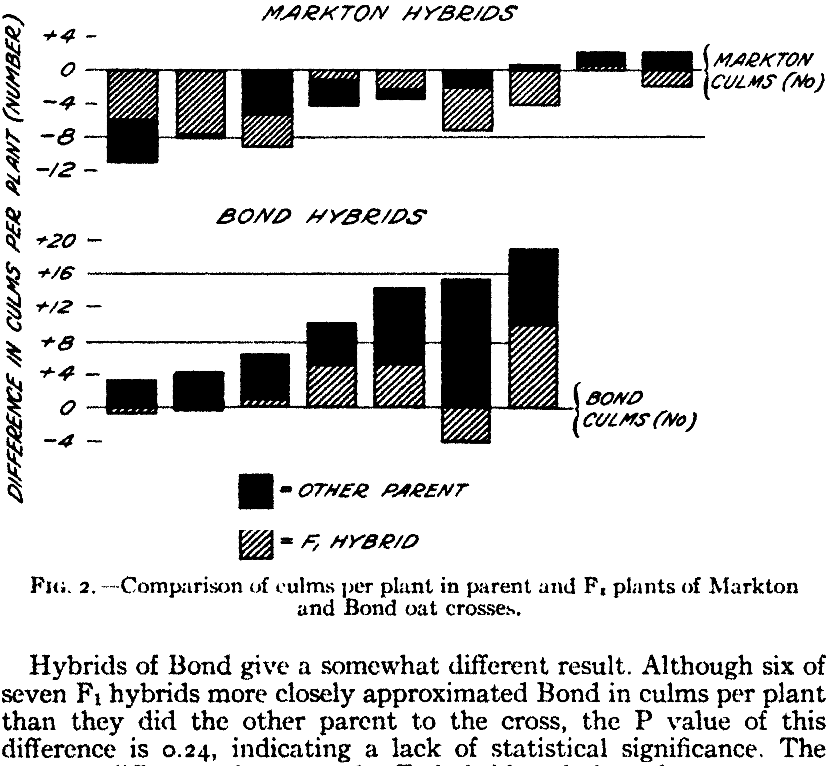

FIG. 2.—Comparison of culms per plant in parent and F_1 plants of Markton and Bond oat crosses.

Hybrids of Bond give a somewhat different result. Although six of seven F_1 hybrids more closely approximated Bond in culms per plant than they did the other parent to the cross, the P value of this difference is 0.24, indicating a lack of statistical significance. The average difference between the F_1 hybrid and the other parent to the cross, however, gave a P value of less than 0.01, indicating a very significant difference. Consequently, Bond definitely tends to influence culms per plant in its hybrids, i.e., the hybrids are inclined to approach the scant tillering characteristic of Bond.

INFLUENCE ON YIELD OF GRAIN

Yield is the result of the combined effects of so many different factors and is of such a "sum-total" nature, that yields of F_1 plants may quite reasonably be taken as indicating the presence or absence of contrasts in yield factors in the parents of the cross. The comparative data presented in Table 1 and shown graphically in Fig. 3

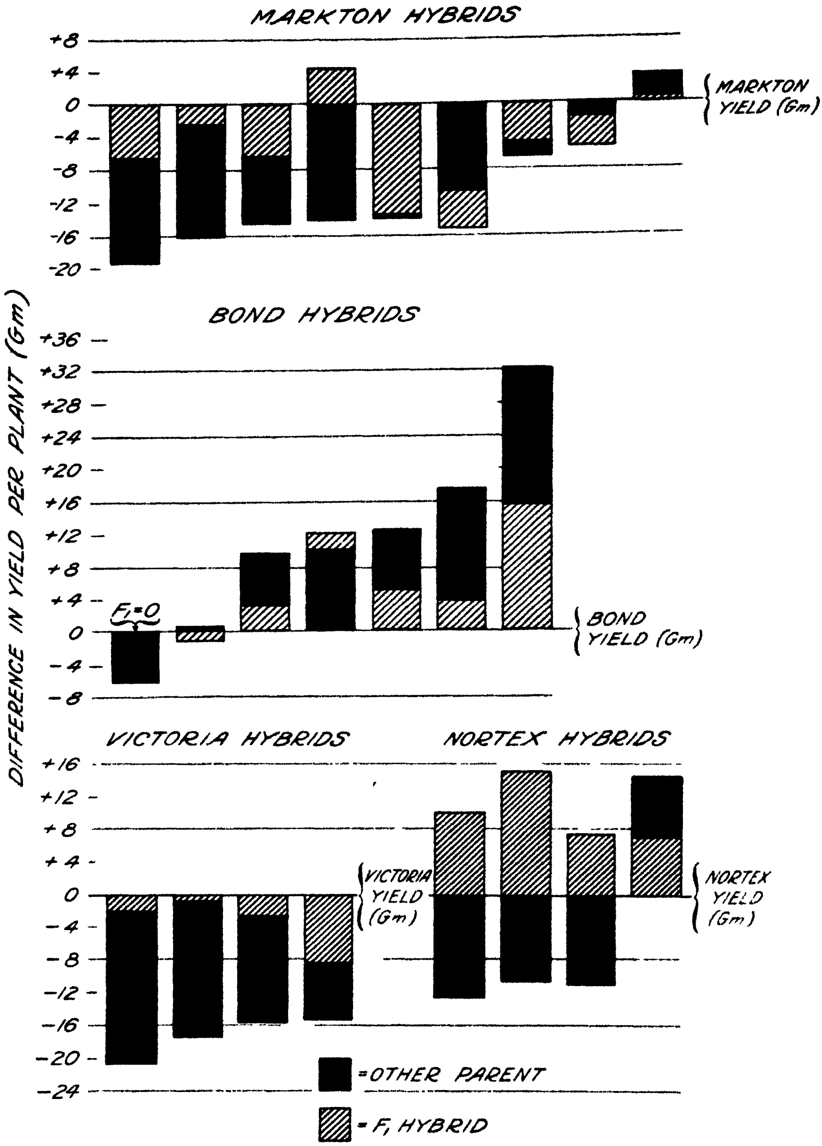

FIG. 3.—Comparison of grain yields of parent and F_1 plants of Markton, Bond, Victoria, and Nortex oat crosses.

indicate that when Markton is crossed with lower yielding strains, the F_1 hybrids usually approximate Markton in yield. Slight indications of hybrid vigor occurred in a few crosses but increases above Markton were almost negligible. The F_1 individuals of four of nine crosses more closely approached Markton than they did their other parent. Markton yielded significantly more than its hybrids which in

turn yielded markedly above their other parents. The P value of these differences was 0.03 in the one case and 0.15 in the other. Consequently, Markton gives indications of raising yield in its F_1 progeny and the varieties crossed with it evidently contributed no additional factors of importance except in one cross.

Crosses of Black Mesdag, Richland, and Nortex gave results somewhat similar to one another in that hybrid vigor more frequently resulted regardless of whether the strains crossed with these varieties yielded less or more than they. This would indicate that these varieties contain factors for yield not present in many of the strains with which they were crossed, and *vice versa*. Consequently, none of these varieties can be considered as especially influencing the yield of their F_1 progeny.

The F_1 hybrids of Black Mesdag and Nortex tended to approach these parents in yield. Richland, on the other hand, indicated the exact opposite

Unfortunately, Victoria was crossed only with varieties which yielded less than Victoria, but indications of its influence were present. When Victoria was crossed with widely differing varieties, some of which yielded far less than Victoria, the resulting hybrids all closely approximated Victoria in yield. Victoria yielded markedly above its hybrids which in turn yielded very significantly higher than their other parent ($P = 0.01$). This probably indicates that the varieties crossed with Victoria contained no yield factors of importance not present in Victoria. Presumably it should be possible to obtain high-yielding segregates from Victoria hybrids.

Bond usually yielded less than the variety with which it was crossed. The relationship between Bond and its hybrids with respect to yield is the exact opposite of that observed in Markton and its hybrids. In Bond crosses the yield of the hybrids exceeded that of Bond but was markedly less than their other parents. Consequently, Bond seems prepotent for its weak tillering habit. Bond hybrids lack yielding ability.

DISCUSSION

The results obtained from a study of the influence of the parent on its F_1 progeny indicate that some varieties tend to influence rather uniformly several characters in their hybrids, whereas others may influence only one or possibly none at all. Obviously, influencing one character may in turn explain the influence on some other; as, for example, Bond being a rather sparsely-tillering oat, the number of culms per plant in F_1 hybrids of Bond were reduced rather uniformly. The number of culms and yield of grain per plant usually being closely associated in cereals may explain why Bond hybrids tend to produce lower yields than are produced by plants of those varieties crossed with Bond. Nortex, on the other hand, is a rather profusely tillering variety. Its hybrids usually approximated it in number of culms per plant but exceeded it in yield ($P = 0.01$). In the progeny of crosses of Nortex hybrid vigor frequently was observed.

As to number of culms, Black Mesdag was somewhat like Bond in breeding, i.e., both produced few tillers, and the F_1 hybrid frequently

bore fewer culms than the variety crossed with Black Mesdag. However, yield and tillers per plant apparently are not always closely associated. Although F_1 hybrids of Black Mesdag usually had comparatively few tillers, they frequently exhibited indications of hybrid vigor in yield to the extent that some hybrids exceeded both parents.

Markton, a tall, high-yielding variety, produced hybrids that tended to approximate it for height, but few F_1 hybrids, resulting from crosses with Markton, exceeded Markton in yield or culms per plant. However, most hybrids of Markton outyielded their other parent. This may be considered as indicating that Markton has the ability to produce promising progeny, whereas Bond, an oat which produced few tillers and small yields, seems to produce progeny inferior to those varieties crossed with Bond.

These studies have indicated that the varieties Markton, Black Mesdag, Victoria, and Bond all apparently influence size characters in their F_1 progeny, although they do not all seem to influence the same character or characters It is of interest in this connection that these varieties are similar in many respects. All are more or less highly resistant to certain physiologic races of smut. It is known that Bond originated as the result of a cross between varieties belonging to the species *Avena byzantina* and *A. sativa*. All of the four varieties mentioned above have certain morphological and physiological characters common to varieties belonging to *A. sativa*, yet all have certain other characters suggesting that they may carry genes derived from *A. byzantina*. This might be considered as a further indication that all had a somewhat similar origin and possibly that all may be the result of crossing between the species *A. sativa* and *A. byzantina*, an indication of exceptional interest in connection with the fact that all apparently influence size factors in their hybrid progeny.

It probably should be mentioned that no smutted individuals were noted among the plants of either the parents or hybrids grown in the course of these experiments. Consequently smut was not a factor in any of the yields recorded.

CONCLUSIONS

A comparison of F_1 oat hybrids with plants of their respective parental lines indicates that:

1. As measured by their hybrids, different oat varieties differ widely. Some apparently influence the size of their F_1 progeny, whereas others do not.

2. The extent of this influence and the number of characters influenced differ with the variety.

3. The difference in height between Markton and Black Mesdag and their F_1 hybrid plants was not statistically significant, but the hybrids were significantly taller than those varieties with which Markton and Black Mesdag were crossed. Conversely, Bond hybrids were significantly taller than Bond and more nearly approximated their other parents in height.

4. Markton apparently lacks the ability to influence the number of culms per plant in its hybrids. They bore significantly fewer culms

than Markton (P less than 0.01). The opposite observation was made on crosses of Bond. The F_1 hybrids of Bond bore significantly fewer culms than those varieties crossed with Bond (P less than 0.01). Bond produces few tillers.

5. Markton and Victoria yielded more than their F_1 hybrids, which in turn yielded very markedly above their other parents. Bond hybrids exceeded Bond in yield but most often yielded markedly less than their other parents. Consequently, Bond seemed to depress yield in its F_1 hybrids, whereas the opposite was indicated by results observed in hybrids of Markton and of Victoria.

6. Bond resulted from crossing a variety belonging to *Avena byzantina* with one belonging to *A. sativa*. Certain characters common to the four varieties, Bond, Victoria, Markton, and Black Mesdag, suggest that they all may have a similar origin or all may have resulted from species hybrids, which is of special interest in connection with indications that all apparently influence somewhat the size characters in their F_1 progeny.

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THE STIMULATION OF SEEDLING PLANTS BY ORGANIC MATTER[1]

J. R. PILAND AND L. G. WILLIS[2]

THE value of organic matter in soils has been recognized for centuries. It has been ascribed to improvement in the water-holding capacity and the physical condition of the soil and to the effect on soil microflora. Without minimizing the importance of the first two a critical analysis of the last raises considerable doubt as to the completeness of the explanations of the functions of the microorganisms. Opinions are given that they increase the availability of plant nutrients in the soil, stimulate nitrification, and otherwise favor the growth of plants by direct action.

Ordinarily it is considered that large amounts of organic matter such as may be supplied by several tons of manure or by plowing under green manure crops are needed. Following the completion of some investigations of the peculiar properties of peat soils[3] from which it was concluded that the decomposition products of the organic matter were injurious because of the reductive properties, a question was raised whether this same characteristic might not be favorable if the activity of the organic matter were not too intense.

In manures the active forms of organic matter are partially eliminated by digestive processes. With raw materials the same effect is produced by composting or allowing them to remain in the soil for a short period before planting. All of these provide a relatively abundant supply of organic matter of low activity that will provide a lasting effect.

Little is known of the fundamental principles governing the growth-promoting effects of decaying organic matter. Considerable attention has been directed recently to evidence that these are produced by specific action of certain definite chemical compounds. No serious attempt has been made to determine the mechanisms by which these compounds become effective. Little attention has been given to the possibility that the results can be attributed to a general property, common to a wide range of organic as well as inorganic compounds, which relate to the oxidation-reduction equilibrium.

Although a fairly satisfactory hypothesis regarding the character of this equilibrium has been developed, no attempt will be made at this time to express it formally. It is necessary to state, however, that the plan of the following experiment was developed in accordance with some of the concepts inherent to the hypothesis and that the use of copper and manganese as variables was not casual. The

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[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, State College Station, Raleigh, N. C. Published by consent of the Director of the Agricultural Experiment Station as No. 94 of the Journal Series. Presented before the Division of Fertilizer Chemistry at the ninety-second meeting of the American Chemical Society in Pittsburgh, Pa., Sept. 7–11, 1936. Received for publication January 23, 1937.

[2]Assistant Soil Chemist and Soil Chemist, respectively.

[3]WILLIS, L. G. Some potential changes induced by liming suspensions of a peat soil. N. C. Agr. Exp. Sta. Tech. Bul. 47. 1934.

influence of other factors can be forecasted with some confidence, but for the present it seems desirable to avoid the confusion of ideas that would result from expansion of the discussion beyond the details of the experiment.

PRELIMINARY EXPERIMENTS

Before any comprehensive experimental project was attempted, a test was made of the effect of ashless filter paper in non-sterile media on the growth of wheat seedlings. These were planted in 150 ml. pyrex beakers containing ignited white sand to which a complete mineral nutrient solution, including copper, manganese, and boron, was added. One disc of 11-cm ashless filter paper was shredded and mixed in the sand of one culture while the other had no organic matter added. Both cultures were inoculated with an equal amount of a soil suspension. The composition of the nutrient solution used will not be given as it has no particular significance.

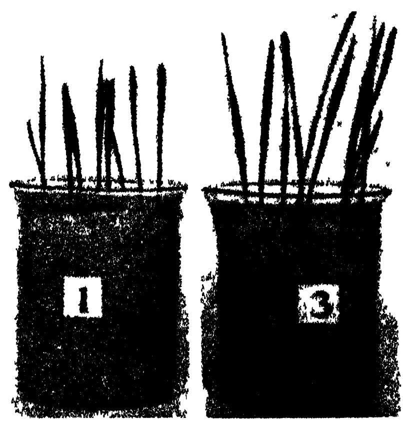

FIG. 1.—Wheat seedlings in ignited quartz sand with complete inorganic nutrient. (1) Without organic matter; (3) with ashless filter paper.

The development of wheat seedlings 6 days after planting is shown in Fig. 1. The difference in size persisted for 19 days when this detail of the work was discontinued.

Following this, a similar test was conducted with seed of a wide range of plants. Tobacco, petunias, lettuce, mustard, and turnips all gave responses to organic matter similar to those obtained with wheat

FINAL EXPERIMENT

METHODS

For the final experiment it was necessary to design apparatus that would maintain a constant rate of supply and renewal of the nutrient solution as well as to eliminate any possibility of physical effects of undecomposed organic matter and to introduce the copper and manganese in such a manner that they would have no influence on the processes of decomposition. A diagram of the apparatus is shown in Fig. 2.

These bottles containing the nutrient solutions were a modification of the Marriot bottle principle with no positive siphoning effect so that the solution flowed from each one at a uniform rate as air was forced into it by the rise of water in bell jars placed in a galvanized iron tank. From the nutrient storage bottles the solution passed into siphoning tubes either directly or through a filter tube containing one 11-cm disc of ashless filter paper shredded and mixed

with ignited white sand. The nutrient, which was uniform for all cultures, had the following composition per liter:

74.6 mgms $CaCl_2.6H_2O$
47.5 mgms $NaNO_3$
36.9 mgms $(NH_4)_2SO_4$
61.9 mgms $MgSO_4.7H_2O$
57.0 mgms K_2HPO_4
44.6 mgms KH_2PO_4
7.5 mgms $CaSO_4.2H_2O$
0.25 p.p.m. H_3BO_3
pH 7.3

The siphoning tubes discharged 50 ml. of the solution intermittently onto a small glass plate placed on the surface of the ignited white sand in the plant

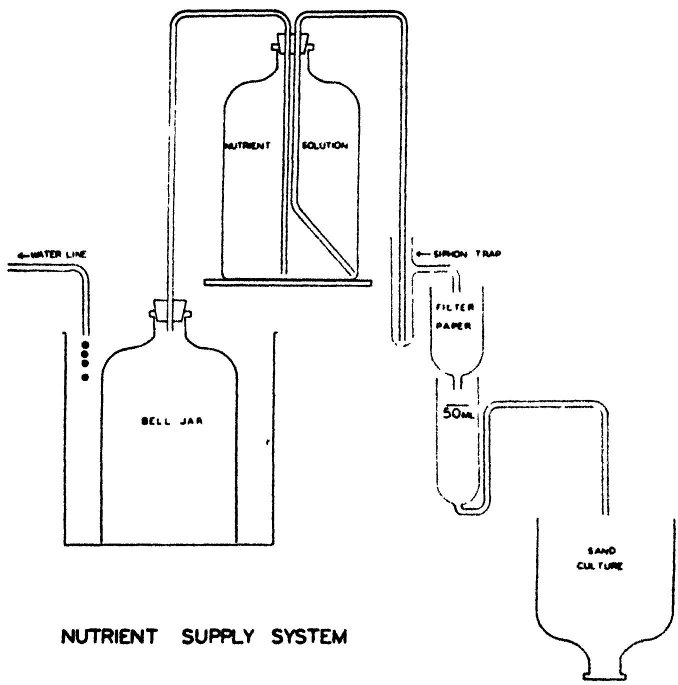

FIG. 2.—Diagram of nutrient supply system.

culture jars. By this method the solution was distributed evenly over the surface of the sand and each addition displaced from the jars, through the bottom, all of the previously added solution that was not required to saturate the sand. The rate of supplying the nutrient was approximately 2 liters in 3 days. All of the surfaces in contact with solutions were glass. The filter paper containers and culture jars were inoculated with a soil suspension. The assembled apparatus is shown in Fig. 3.

SUPPLEMENTARY TREATMENTS

For comparison with the filter paper used as a source of organic matter, 5 milligrams of gossypol, a non-nitrogenous component of cottonseed meal, was

added directly to each 2 liters of the nutrient solution in the containers of a separate series. While the results are of considerable interest, they do not contribute anything of fundamental significance to the work.

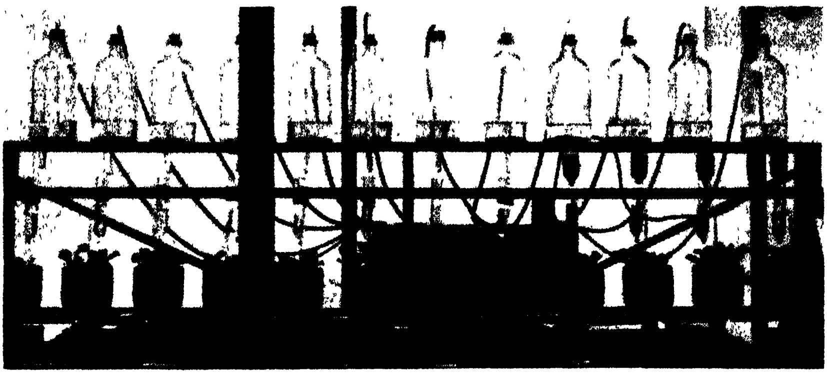

FIG. 3.—Twelve-unit series of sand cultures.

Five-tenths of a gram of ferric oxide was mixed uniformly with the sand of the culture jars at the beginning of the experiment except that in the series with filter paper 0.4 gram was put into the culture jars and 0.1 gram into the tubes with the paper. Copper and manganese sulfates were added in amounts supplying 0.0025 mg of the metallic element to the plant cultures through the siphoning tubes at weekly intervals.

RESULTS

Seed of mustard were planted in the sand and thinned soon after germination to 10 plants to each jar. The growth after 29 days is shown in Fig. 4. When the visible differences were most distinct. Seven days later the plants were removed and the sand washed from the roots as completely as possible. The weights of the sand-free dry matter are given in Table 1.

TABLE 1.—*Dry weight of mustard plants.*

Treatments	Organic matter added					
	None		Gossypol		Filter paper	
	Tops, grams	Total plant, grams	Tops, grams	Total plant, grams	Tops, grams	Total plant, grams
None	0.6060	0.8388	1.0756	1.3514	1.7634	2.4750
Copper	1.6488	2.2162	1.9070	2.5882	1.7508	2.4822
Manganese	1.8744	2.6634	1.6530	2.2406	2.1916	2.9822
Copper-manganese	1.5362	2.1402	1.7384	2.3708	2.6712	3.5472

DISCUSSION

COPPER-MANGANESE-ORGANIC MATTER RELATIONSHIP

From these results and the illustrations it is evident that the decomposition product of the filter paper greatly stimulated the

growth of the plants. Copper and manganese had a beneficial effect, although there was no visible evidence of a deficiency of either of these elements when neither was supplied. After the work had been completed, an analysis showed a trace of manganese in some of the unused sand so it is impossible to state whether the organic matter would have been effective in the virtual absence of either of these two elements. Neither is it possible to state that the cultures to which no organic matter was added were entirely free of organic matter, since it was impossible to control the growth of algae or to

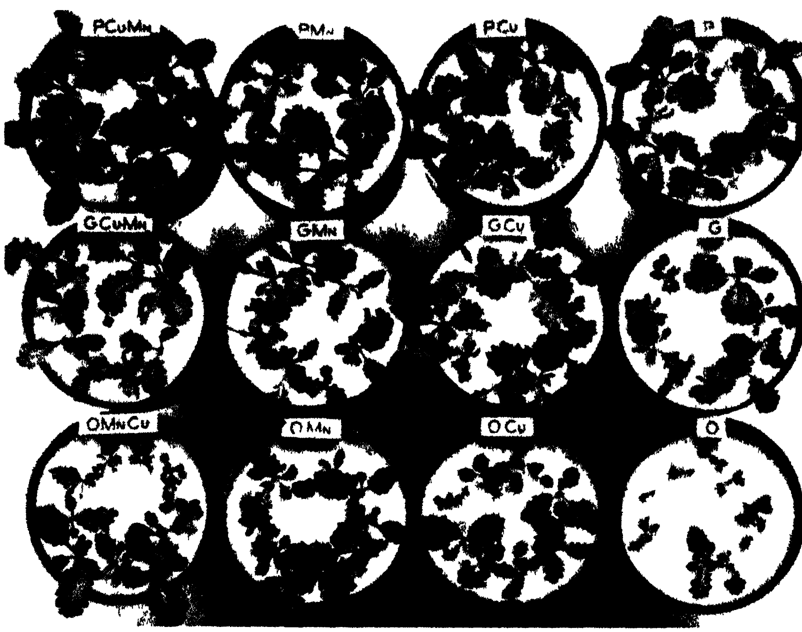

FIG. 4.—Growth of mustard seedlings in sand cultures. O, without organic matter; G, with gossypol added to nutrient; P, with nutrient percolate from inoculated filter paper.

eliminate organic matter from the plant roots. It is not improbable that the stimulation of growth in the cultures receiving organic matter without added manganese or copper is a resultant of the effect of manganese in the sand and that the increases shown with copper and manganese on the cultures without organic matter reflect the supplementary influence of unavoidable traces of organic matter. In the latter case the size of plants determine the amount of organic exudate. So a tentative interpretation is offered that the plants in non-sterile media furnish, in some degree, the growth promoting stimulus. In these cultures there is no dependable evidence that copper or manganese would produce a stimulation of growth in the complete absence of organic matter nor that organic matter would produce an increase in the complete or virtual absence of copper or

manganese. By a process of extrapolation, however, a tentative assumption can be reached that above the limits of extremely small amounts of copper or manganese the effects of these ingredients are dependent upon organic matter, whether this be added to the soil or excreted from plant roots.

The reactions involved are in no sense associated with the deficiency problem as it is ordinarily understood since the copper and manganese added to some of the cultures produced comparable results as evidenced by plant growth. In the cultures receiving gossypol, copper was more effective than manganese or the two elements together In the filter paper series, however, neither copper nor manganese was distinctly beneficial, although a combination of the two elements produced a definite increase in growth. If these two series were analyzed separately, it would seem that in the one supplied with gossypol, copper and manganese perform the same function, but with different efficiencies, while in the latter it would appear that both were necessary. Since the plants in the filter paper series without added copper or manganese made better growth than the corresponding culture in the gossypol series it must be concluded that the effect of copper or manganese is relative to some undetermined property of the organic matter.

A question may be raised regarding the influence of organic matter. It is doubtful that with the method of supplying the nutrient solution to the culture jars the carbon dioxide content could have been any greater than that of equilibrium with air. The method of bubbling air through the solution in the storage bottles before delivery would insure this equilibrium. The flow of the nutrient through the filter paper might disturb this, but it would be re-established by later contact with air before delivery to the cultures. It is doubtful, therefore, that carbon dioxide, physical effects, or water relations govern the results obtained with organic matter.

The nutrient solution was fairly well buffered, but there was a remote possibility of the production of an organic acid in the decomposition of the filter paper that would lower the pH of the nutrient. Such a change should be reflected in a solvent effect on iron, the only relatively insoluble essential component in the cultures. The iron contents of the aerial parts of the plants are shown in Fig 5 together with the dry matter produced.

IRON CONTENT OF PLANTS

It is evident that the iron content in percentage of dry material is decreased by the organic matter, and since the addition of copper and manganese further decreased the iron content, it is probable that the manganese content of the sand was significant. The scale on the diagram is adjusted to show the interesting relation that in nearly all cases the production of dry matter is inversely proportional to the percentage of iron content. With two exceptions the total iron content in each series did not vary significantly, although that of the plants in the filter paper series was uniformly less than in the other two.

It is apparent that there was no solvent effect that could account for the increases shown in growth in the cultures supplied with or-

ganic matter. As to the inverse relation between growth and iron content, cause and effect cannot be distinguished.

PRACTICAL INTERPRETATION OF RESULTS

The application of the foregoing results to the problems of soil fertility provides definite evidence of an unrecognized function or organic matter in general and of organic ammoniates in fertilizers in particular. It is apparent that the attention that has been given to the insoluble nitrogen in the latter has been to some extent misdirected. A serious defect of field experiments in which the various organic ammoniates have been compared on the basis of equivalent amounts of nitrogen is exposed. The rational basis for comparison now seems to be a uniform rate of application of organic matter in which the variable factor will be the activity of the decomposition products of this component.

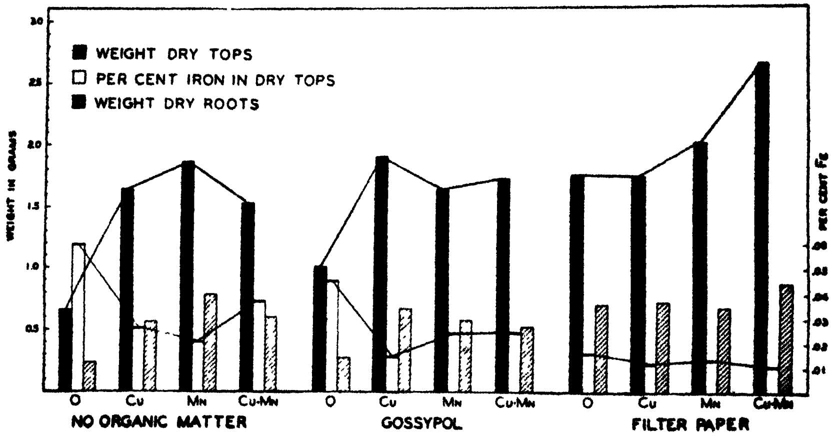

FIG. 5.—Weight of dry mustard plants and iron content of aerial parts.

The observation has frequently been made that crops make a better early growth when the nitrogen is supplied in the form of certain high grade organic materials. This has been interpreted as indicating a more available form of nitrogen. Actually, the result indicates a greater gross efficiency of the material and the activity of the organic matter independent of the nitrogen content may constitute a very great part of the efficiency factor. There is no experimental evidence from which the activity of organic materials can be derived. Research on this problem is being developed as rapidly as possible.

The term organic matter has been adopted for convenience. More accurately, the problem concerns those organic compounds that liberate energy in the process of natural decomposition by microorganisms.

It has been customary to ridicule farmers for preferring bulky fertilizers with an odor indicating putrefaction. Insofar as bulk signifies the presence of organic matter and odor indicates the activity of decomposition, the preference of farmers seems to be justified.

In earlier reports[4] evidence has been given to show that copper will reduce the iron content of plants or the activity of iron within plants. Now it seems that this effect of copper is in some degree dependent upon a property of organic matter. Possibly only the iron problem is involved insofar as the effect of copper and manganese is concerned, but there is a strong probability that the whole oxidation-reduction reaction by which the iron factor is controlled is of greater significance.

Conversely, the effect of organic matter seems to be dependent on a reaction in which copper or manganese is involved. If organic matter provides some specific growth-promoting component, it is difficult to explain the effect of these elements. In the highly organic soils copper might be considered as an antidote for an excess of the growth-promoting component. It would seem inconsistent, therefore, to expect the copper to activate small amounts of the same material.

There is an extensive field for further research on this problem. Observations of the growing seedlings in the foregoing experiments indicate a possibility that the stimulating effect of the organic matter may be most pronounced in the early stages of growth. Later, it is probable that plants can provide this factor by their own physiological processes. It can be expected, however, that different species will vary as regards this capacity.

In some degree, possibly entirely, the incorporation of organic matter into the soil may eliminate the need for organic compounds in fertilizers. The latter should be especially valuable where the method of cropping and soil management do not insure an abundance of organic matter.

The other phase of the problem relates to the supply of copper or manganese. Possibly the general superiority of the oil seed meals and the animal by-products depends in part upon their rate of decomposition and the traces of copper or manganese they contain. This introduces the possibility that the efficiency of some of the low grades of organic ammoniates or even non-nitrogenous organic fillers can be increased by the inclusion of copper or manganese in the fertilizer formula. The amounts of these elements needed will depend upon the perfection of mixing, a few pounds of the sulfates in a ton being sufficient if they are perfectly disseminated.

SUMMARY

Organic materials such as gossypol and the decomposition product of filter paper stimulates growth of mustard seedlings. The effect of copper and manganese is additive to that of organic matter.

Growth is inversely proportional to the percentage of iron in the tops of the mustard plants, and the plants with the filter paper treatments had, in general, less total iron than the other two series.

It is concluded that this phenomenon is associated with the oxidation-reduction equilibrium, that the results pertain to an important function of organic matter in soils and of organic ammoniates in fertilizers, and that copper and manganese promote a favorable reaction.

[4]WILLIS, L. G., and PILAND, J. R. The influence of copper sulfate on iron absorption by corn plans. Soil Science, 37:79–83. 1934.

NOTES

TERMINOLOGY ON PHOTOPERIODISM AND VERNALIZATION

IN studying literature dealing with photoperiodism and vernalization, one frequently encounters confusion in respect to the use of the appropriate technical terminology. Naturally this may lead to misinterpretation of experimental work and misunderstanding of results obtained.

With the object of clarifying to some extent the existing situation, the following list of definitions is presented herewith. The writer will appreciate information on possible additions to or corrections of this terminology.

Photoperiod.—Length of daily exposure to light (Garner and Allard).

Photoperiodism.—Response of plants to photoperiod (Garner and Allard).

Long-day plants.—Species, varieties, and strains in which the flowering period is accelerated by a *relatively* long daily exposure to light, usually more than 12 or 14 hours (Garner and Allard).

Short-day plants.—Species, varieties, and strains in which the flowering period is accelerated by a *relatively* short daily exposure to light, usually less than 12 or 14 hours (Garner and Allard).

Photoperiodic induction.—The carry-over effect of a photoperiod conducive to sexual reproduction to one opposite to it and *vice versa*. Also the transfer of photoperiodic stimulation to a non-treated part of the same plant (Lubimenko and Sceglova).

Photoperiodic after-effect.—The same as photoperiodic induction (Maximov). Plants may exhibit also "temperature" and possibly other "after-effects".

Photoperiodic adaptation.—The adaptation of plants, in their native or artificial habitat, to a definite length of day or latitude (Lubimenko). Sometimes confused with photoperiodic "induction" or "after-effect".

Thermoperiodic adaptation.—The adaptation of plants, in their native or artificial habitat, to periodic changes in temperature (Lubimenko).

Photoperiodic inhibition.—Inhibition or retardation of growth, primarily of the main axis, by certain photoperiods (Murneek).

Jarovization.—A preliminary treatment of seeds (with cold, heat, darkness, light, etc.) to induce early reproduction in crop plants (Lysenko).

Vernalization.—English equivalent of the word jarovization (Whyte and Hudson).

Physiological predetermination.—Effect from treatment or condition of seed which influences the future development of the plant (Kidd and West).

Phasic development.—A theory that in their development plants pass through definite successive stages or phases (Lysenko).

—A. E. Murneek, *Missouri Agricultural Experiment Station, University of Missouri, Columbia, Mo.*

APLOPAPPUS FRUTICOSUS OR BURRO WEED

WHILE studying range ecology on the Santa Rita Range Reserve, a division of the Southwestern Range and Forest Experiment Station of the Forest Service, located about 40 miles south of Tucson, Arizona, the interest of the writer was drawn to the burro weed, as *Aplopappus fruticosus* is commonly called in the Southwest. This plant is becoming a serious pest on many grazing areas of the

Southwest. It has no forage value, but will be eaten when other food is absent in which case it generally poisons the animals. It is the purpose of this note to report briefly the results of two summers' research on *A. fruticosus* and suggest means of eradication.

It was decided to establish two 100 x 50 meter plats with a strip in between. One plat was fenced to exclude cattle. The second plat was to be left for open grazing. One-half (50 x 50 meters) of each plat was burned, while the remainder was left in its natural condition. Within each of the four areas, five 1 x 10 meter plats were systematically established. The vegetation in each of these was listed and the first and last meter quadrat of each plat was mapped with a pantograph and each 1 x 10 meter plat was photographed. These data were collected each spring and fall.

Before the burning was done the *A. fruticosus* plants on each area were counted. One year later, when it was felt that those plants which had recovered would commence growth, the surviving plants were counted. From these figures the percentage of survival was determined (Table 1).

The areas were burned July 18, 1932. As the plants were rather green at that time and did not burn readily, they were first sprayed with crude oil. Even the addition of the oil did not cause the plants to burn as easily as was hoped. It is thought that earlier in the spring—about the time the sap begins to rise in the plant—would be a more favorable time for burning than in the summer. At this time also, less damage would be done to the grass and the burro weed plants should burn more readily.

Grass density was determined and growth measurements (heights and stem counts) of 30 plants each of *Bouteloua rothrockii, Aristida divaricata* and *A. californica*, and *Valota saccharata* were taken on each plat. Data for this were obtained only one season, therefore, it is not thought that any definite conclusions can

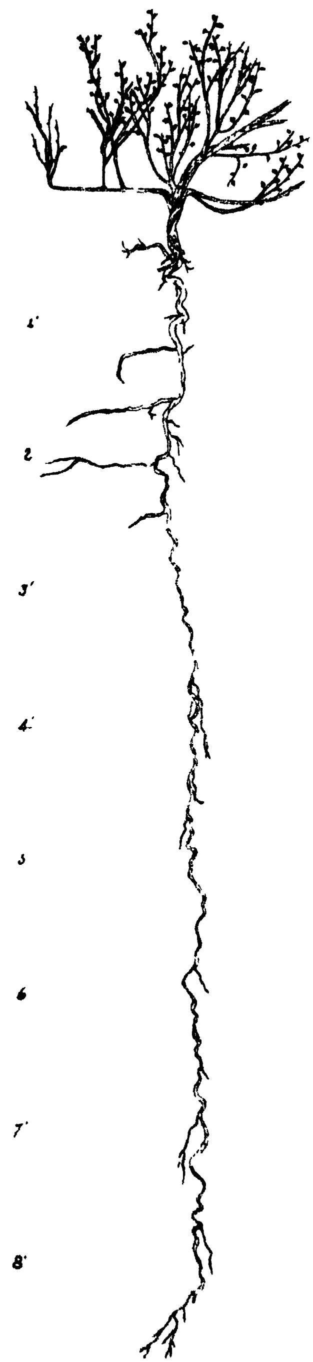

Fig. 1.—Root system of *Aplopappus fruticosus*.

be drawn. It was found that height growth was greatest on the unburned plat of the protected area. This was only slightly greater however, than that for the burned plat of the same area. Increase in stem numbers was slightly greater on the burned plat of the protected area.

TABLE 1.—*Number of plants before and after burning and survival in percentage on cattle exclosure and grazed areas.*

Area	Number of plants before burning	Survival after burning	
		Number of plants	%
Cattle exclosure	7,477	400	5.35
Grazed	10,139	723	7.13

Later in the season an area 50 x 50 feet was chosen for determining the efficiency of grubbing to eradicate this plant. All the burro weed plants on this area were grubbed out and removed and the area then handled the same as the other plats. Where an area is open to grazing, the grubbed plants should be left to protect the grass, otherwise it will be grazed too closely and be killed. Such was the case in this instance and few data were obtained. Grubbing is to be recommended only where a relatively few plants are found on an area. These should be cut 2 or 3 inches below the surface of the soil.

A. fruticosus may be considered an invader in the range area. When drouth, grazing, or a combination of these have weakened the grasses and left bare soil areas, burro weed can gain a foothold. The seeds being light and silky are carried by the wind for long distances. This plant was a tap root which may extend 7 feet or more in depth (Fig. 1). As long as a good grass cover is maintained the burro weed cannot gain a foothold. Possibly this is because the fibrous root system of the grass utilizes the moisture from precipitation before it can penetrate deeply enough to be available for the deeper-rooted plant. However, when once the burro weed has gained a start, grazing favors it by reducing the competition of the grass while the shrub is unpalatable to livestock and will be eaten only in case other feed is lacking.

Burro weed cannot be considered solely as a troublesome weed because it certainly protects the soil from erosion, retards runoff, and furnishes conditions favorable to the germination of the grass seeds. In time, no doubt, under proper grazing practices the grasses would replace the burro weed.—B. IRA JUDD, *Mandan, N. D.*

BOOK REVIEWS

CYTOLOGY OF FRUITS AS RELATED TO PLANT BREEDING

By B. R. Nebel. Stuttgart: E. Ulmer. Garten- und Weinbau. Heft 29, 58 pages, illus. 1937. RM $1.65.

IN this monograph, which is in German, the author describes and illustrates the cell and its contents. The chromosomes and their method of division are given particular attention. The gene conception, Mendelism, and polyploidy are also clearly explained. After treating on the basic principles of the science of breeding, specific fruits are given consideration.

In the section on the apple and pear, the chromosome numbers are given and the characteristics and origin of the triploids noted. All the known diploid and triploid apples and pears are listed and the tetraploid wild apples are mentioned. The supposed origin of the apple and pear are briefly noted as also the available information in regard to inheritance of characters. The plum, cherry, peach, apricot, nuts, strawberry, blackberry, raspberry, blueberry, currants, and grapes are similarly treated, the amount of data varying directly with the information available.

The article closes with a brief discussion on crossing-over, polyploidy, and mutations, and how they may be induced. Both the scientific and practical worker should be interested in this presentation for it treats on both aspects in an admirable way. (R. W.)

THE EXPERIMENTAL PRODUCTION OF HAPLOIDS AND POLYPLOIDS

Cambridge: Imperial Bureau of Plant Genetics. 28 pages. 1936. 5/.

THIS publication will prove of greatest interest to experimental plant cytologists and plant breeders since it concisely summarizes the most important literature bearing upon artificial polyploidization and haploidization, which is the most important general problem in the production of new forms.

Somatic and gametic "ploidization" as induced by chemicals, temperature, X-rays, centrifuging, callus formation, and other agents are referred to under brief separate headings. There is a chapter on polyploidy as the result of hybridization listing the economically and genetically important genera. A bibliography and a subject index are appended.

The publication shows how much easier progress has been in certain genera than in others and how intensely necessary the Imperial Bureau apparently considers further systematic work along these lines. (B. R. N.)

SOUTH AMERICAN POTATOES AND THEIR BREEDING VALUE

Cambridge: Imperial Bureau of Plant Genetics. 15 pages. 1936. 3/6.

A BRIEF summary is set forth of the findings of recent Russian expeditions into South America to study the origin and diversity of potatoes in their native habitat with the view of utilizing the in-

formation thus obtained in developing future breeding programs for this important food plant.

The great multiplicity of forms and species associated with the unusual range of conditions under which potatoes grow in South America is cited, with the suggestion offered that the material uncovered by the Russian workers will prove a valuable source of new characters in almost all branches of potato breeding.

Sections of the monograph deal briefly with systematics and cytology, origin, frost resistance, disease resistance, the use of *S. andigenum*, short dormancy, and culinary quality. A tabulation of the cytological composition of wild and cultivated potatoes is included, together with a bibliography of 27 titles. (J. D. L.)

THE SOILS OF IOWA

By P. E. Brown, Ames, Iowa: Iowa Agr. Exp. Sta. Special Report. No. 3. 266 pages, illus. 1936. 50 cents.

THIS report gives descriptions of the 260 soil types mapped in Iowa over the past 24 years in the survey of 88 of the 99 counties in the state. These soil types have been studied in the field by profile and their characteristics determined. They have been analyzed in the laboratory and greenhouse and field tests have been run on the more important types for fertility studies. There are drawings showing profile character, maps showing the occurrence in the state, and descriptions of the variations of the types as mapped in different counties.

Chapters in the report discuss the geology of the state, the large soil areas as distinguished, the methods of making the survey with definitions of all soil terms, the results of the chemical analyses of the soils analyzed statistically, the general productivity or potential fertility ratings of the types, and the ratings of all types in individual counties for the different general farm crops, and the average results of the cooperative soil experiments on the major soils showing the effects of the application of the Iowa system of soil management on soil fertility.

CORN AND CORN GROWING

By Henry A. Wallace and Earl N. Bressman. New York: John Wiley & Sons, Inc. Ed. 4. VII + 436 pages, illus. 1937. $2.75.

THE popularity of this book is shown by the fact that the first three editions, published in 1923, 1925, and 1928, respectively, have been exhausted, requiring the publication of this fourth edition, which has been revised with much new material added, making this new edition 436 pages, as compared with 371 pages in the preceding edition.

In particular, the subjects of corn genetics and corn economics have been considerably enlarged. For example, in the former edition, there was only one chapter on "Corn Economics," whereas the revised edition contains three new chapters entitled "Economic Factors Affecting Corn Production," "Economic Factors Affecting Corn Prices,"

and "The Interrelationship between Corn and Hogs." The appendix has also been revised and enlarged, and the statistics brought up to date.

All phases of corn growing, including planting, fertilizing, cultivating, harvesting, seed selection, corn judging, economics of production, by-products, varieties, and regional adaptations are discussed. The technic of four methods of corn breeding is explained, with suggestions for the most practical applications for farmers. This book is well suited for a classroom text and as a practical treatise for farmers, and the revised edition should prove increasingly popular. (C. B. S.)

AGRONOMIC AFFAIRS

SUMMER MEETING OF CORN BELT SECTION

THE summer meeting of the Corn Belt Section of the American Society of Agronomy will be held at the Michigan State College, East Lansing, Michigan, June 22 to 24. The field program will feature forage and pasture crops, plant breeding, soil fertility and crop rotation studies, and experiments with muck soil management. Special conferences are being arranged for those working on soft wheat improvement and for the soil conservation group.

NEWS ITEMS

C. P. BLACKWELL, Dean of the College of Agriculture and Director of the Oklahoma Agricultural Experiment Station at Stillwater, died on March 4. Prior to taking up his duties at Stillwater in 1929, Professor Blackwell had served in the agronomy departments of the University of Texas, Clemson College, and Cornell University. He was also associated with the Soil Improvement Committee of the National Fertilizer Association for a period of years.

DR. H. K. HAYES, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, has returned from a year in China, where he has been directing the training of graduate students and superintending the general research program in agronomy and plant genetics.

DR. E. G. ANDERSON, California Institute of Technology, has returned to Pasadena after spending the winter quarter at the University of Minnesota as guest professor in the Division of Agronomy and Plant Genetics. Dr. Anderson taught courses in advanced plant genetics and otherwise assisted in direction of graduate students during his time at Minnesota.

THE DIVISION OF FORAGE CROPS, Bureau of Plant Industry, has issued a supplemental list of 58 titles that should be added to a "Digest of Pasture Research Literature in the Continental United States and Canada, 1885–1935". This supplemental list has been mimeographed on one side of the paper so that users of the "Digest" can cut

the entries and insert them where they belong. It is now available for distribution and application should be made to the Division of Forage Crops, Bureau of Plant Industry, U. S. Dept. of Agriculture.

DR. A. L. GRIZZARD, formerly Associate Agronomist at the Virginia Agricultural Experiment Station resigned, effective January 1, 1937, to accept a position as Assistant Agronomist with the National Fertilizer Association with headquarters at Washington, D. C. He will give major consideration to pasture improvement as he had in Virginia for the past few years. R. E. O'BRIEN, a graduate student in the Department of Agronomy at Virginia Polytechnic Institute, Blackburg, has been appointed Assistant Agronomist at the Virginia Experiment Station and will assume the duties formerly carried by Dr. A. L. Grizzard.

P. H. DEHART, a graduate of Virginia Polytechnic Institute, has been appointed to the position of Instructor in Agronomy at that institution. He will give full time to teaching duties. Mr. Dehart had been County Agent of Princess Anne County, Virginia, prior to accepting his new position.

K. M. OLIVER and H. H. PERRY, both graduates of the Virginia Polytechnic Institute, have recently been employed by the Virginia Agricultural Experiment Station as Assistant Agronomists and have been assigned to soil survey work.

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THE RELATION OF AWNS TO THE PRODUCTIVITY OF OHIO WHEATS[1]

C. A. LAMB[2]

IN the Ohio wheat breeding program, the possible influence of the awn on yield is peculiarly important. Farmers have a marked antipathy to bearded varieties, not alone because they are unpleasant to handle, but also because they do not make as good shocks, nor cap as well. In a region with frequent heavy thunder showers, these considerations are by no means negligible, and unless there is sound basis for urging growers to adopt bearded varieties, the obvious advantages of beardless wheats would justify the practical elimination of bearded segregates from the breeding nursery

REVIEW OF LITERATURE

The statement has recently appeared that bearded varieties are rapidly replacing beardless varieties in the United States (9).[3] To test the validity of this statement, the data in Table 1 were compiled from the distribution of classes and varieties of wheat given by Clark and Quisenberry (3). Separation into bearded and beardless groups follows Clark, Martin, and Ball (2) and Clark and Bayles (1). Awnless and awnletted varieties were grouped as beardless wheats. In the few cases where it could not be determined from these sources whether or not named varieties were bearded, acreages were omitted. Such omissions were negligible. Since durum wheats are all bearded, they were not considered at all.

A study of Table 1 shows that for the United States as a whole bearded wheats occupied 49.6% of the acreage in 1919, and that the acreage increased to 57.2% in 1929. However, consideration of the data by classes shows that this increase was due not to bearded varieties supplanting similar beardless ones, but rather to a shift in the class of wheat grown. The increase in acreage of hard red winter wheat from 1919 to 1929 was roughly 3,600,000 acres, made up almost exclusively of awned varieties. The decrease in acreage of soft red winter wheats over the same period was approximately 11,000,000 acres, of which about two-thirds were

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Also presented at the annual meeting of the Society held in Washington, D. C., November 20 to 22, 1936. Received for publication February 2, 1937.
[2]Associate in Agronomy.
[3]Figures in parentheses refer to "Literature Cited", p. 347.

TABLE 1.—*Acreages of bearded and beardless wheats in the United States, 1919–1929.*

Area or class of wheat	Bearded		Beardless		Total acres*
	Acres	%	Acres	%	
In 1919					
United States	31,322,800	49.6	31,864,610	50.4	63,187,410
Hard Red Winter	21,720,500	99.9	8,100	0.1	21,728,600
Soft Red Winter	6,692,400	32.8	13,699,110	67.2	20,391,510
Hard Red Spring	2,332,400	14.2	14,099,100	95.8	16,431,500
White	575,900	12.5	4,027,400	87.5	4,603,300
Ohio	398,300	17.0	1,943,100	83.0	2,341,400
Michigan	295,900	42.1	406,910	57.9	702,810
Indiana	661,500	26.6	1,826,500	73.4	2,488,000
Delaware	29,000	48.8	30,400	51.2	59,400
In 1929					
United States	31,223,251	57.2	23,379,645	42.8	54,602,896
Hard Red Winter	26,198,944	98.7	349,587	1.3	26,548,531
Soft Red Winter	3,245,656	31.8	6,954,875	68.2	10,200,531
Hard Red Spring	983,906	7.3	12,502,764	92.7	13,486,670
White	793,030	18.2	3,572,419	81.8	4,365,449
Ohio	168,383	11.5	1,292,173	88.5	1,460,556
Michigan	281,365	39.1	438,034	60.9	719,399
Indiana	319,312	22.6	1,095,823	77.4	1,415,135
Delaware	53,480	54.0	45,561	46.0	99,041

*Total acres, excluding acreage where variety was not reported and excluding durum wheats.

beardless varieties. In the white wheats alone had the proportion of bearded wheats increased, but in this instance one variety, Baart, was largely responsible for the shift.

In the important soft wheat area, comprising Ohio, Michigan, and Indiana, beardless wheats are replacing the bearded. Even in Michigan where Red Rock was an excellent relatively new variety, the proportion of bearded wheats dropped slightly. At the present time, this tendency has been greatly accelerated by the rapid increase in acreage sown to Bald Rock.

There is little agreement among investigators as to whether bearded wheats possess higher yielding powers because of the awns, and still more divergent opinion on the physiological function of these organs. Literature reviews are often colored by the convictions of the authors, especially in cases where the earlier workers obtained results that were not clear cut. For example, Hickman (7, 8) is often quoted as reporting experiments in which bearded wheats showed marked superiority. In some seasons between 1880 and 1890 this was the case, while in other years the reverse was true. Summing up the matter, Hickman (8) states as follows:

"*Bearded vs. smooth wheats.*—The average yield of 162 trials of bearded wheat and 234 trials of smooth wheat, extending over a period of 10 years, shows but six-tenths of a bushel difference in the average total yields, which suggests that the one is equal to the other in point of vitality."

Grantham (5) has reported extensive tests of bearded and beardless varieties in Delaware, showing an average yield much in favor of the bearded wheats. He is careful in his conclusions, however, to point out that numbers of his "varieties" may be synonyms, and further that the high-yielding bearded sorts may possess other characteristics upon which their productiveness depends.

Study of Grantham's paper shows that synonymy did influence at least some of the comparisons. For example, in one table, listing 29 smooth and 27 bearded varieties, Fulcaster appears seven times, Mediterranean four times, and Gipsy three times. Thus, 14, or over 50% of the bearded wheats listed, were in reality but three varieties, all of which do well in Delaware. Of the beardless wheats in this same table, four were Poole, three Prosperity, three Red May, two Fultzo-Mediterranean, and two Gold Coin. Of these, Poole is definitely better adapted than the others.

With space planting in centgener plats, Grantham found bearded wheats markedly superior, and he notes that, "The bearded wheats in general tiller more freely, thus providing more heads per plant." It is hard to conceive of this increased vigor of vegetative growth as dependent on, or even related to, awns. There were also differences between the two groups in disease resistance and in winterhardiness.

Although in all probability bearded wheats have some advantage in Delaware, the large differences reported by Grantham must be considered as due in part to factors unrelated to the awn. In 1929, Fulcaster, together with Nittany (a selection from it), occupied 46.1% of the wheat acreage of that state. Leap, however, a beardless variety, had increased from 12,700 acres in 1919 to 36,365 acres in 1929, and was sown on 34.7% of the acreage in the latter year. Fulcaster has always ranked well, but the record of Leap suggests that possibly the presence of awns is not essential to high yields.

Opinion varies as to the possible influence of awns on yield in Ohio and the surrounding soft wheat territory. Specific experiments are lacking, but in some cases bearded wheats are reported to have outyielded beardless varieties consistently in regular variety trials. On the other hand, the opinion has also been expressed that no evidence exists to justify the assumption that the yielding ability of awned and awnless varieties is significantly different. The following observations were made with the object of getting something more tangible as a basis upon which to formulate the wheat breeding policy, and not as an experiment to solve any of the basic questions in the problem.

MATERIALS AND METHODS

It was assumed that bulk hybrids in F_3 or later generations, which were segregating for awns, would be satisfactory material to test the influence of beards on yield. If specific bearded and beardless lines had been selected, there would have been serious danger of error due to differences in yielding ability independent of the awns, unless large numbers had been used. By making the single head the unit studied and by using relatively large numbers, such error could be minimized. Individual plants rather than heads would probably have been preferable, but the difficulties involved in separating plants grown in ordinary rod rows were too great, and serious errors could not have been avoided. There seemed no reason to expect bearded plants to differ from beardless in tillering capacity, and therefore no reason to anticipate error from this source.

Material available for this study in the fall of 1931 was reasonably satisfactory, though not ideal. Six bulk hybrid populations of four different crosses in F_3 and F_4

were selected. In two crosses the bearded parents were true soft wheats, and in two segregates from crosses between hard red winter and soft red winter varieties. In all cases the beardless parent was Trumbull. It would have been desirable to have had hybrids involving a wider range of parent material, but if the usefulness of the awn lies in its physiological function, as is generally assumed, the lack of diversity should not be a serious matter.

In addition to these bulk hybrids, two hybrid selections which proved to be segregating for awns were included. These served to increase the diversity of parent material, and at the same time gave an opportunity to check the comparative value of selected and unselected material. Table 2 gives the parentage of all lots used, together with the generation upon which data were collected in each season.

TABLE 2.—*Percentage and generation of hybrids and selections used in study of bearded vs. beardless wheat.*

Number	Bearded parent	Beardless parent	Generation studies in		
			1932	1933	1934
1	O. S. U. 101-3 (Portage x Fulcaster)*	Trumbull	F_3	F_4	F_5
2	O. S. U. 101-3 (Portage x Fulcaster)	Trumbull	F_3	F_4	F_5
3	O. S. U. 168-10 (Poole x Fulcaster)	Trumbull	F_3	F_4	F_5
4	O. S. U. 168-10 (Poole x Fulcaster)	Trumbull	F_4	—	—
5	O. S. U. 63-8a (Turkey Red x Fulcaster)	Trumbull	F_3	F_4	F_5
6	O. S. U. 63-19 (Turkey Red x Fulcaster)	Trumbull	F_3	F_4	F_5
7 H. S. 205-3†	Kanred	Trumbull	Not bulk hybrids		
8 H. S. 495†	Malakof	Fulhio			

*O. S. U. indicates selection made at the Ohio State University.
†H. S. indicates hybrid selection number.

At harvest each row was pulled and tied in a sheaf. During the winter each tiller was taken separately and the length of straw to the nearest inch and length of head to the nearest quarter inch recorded. The heads were then carefully threshed by hand, the kernels counted and weighed, and the 1,000-kernel weight calculated. The data were divided into two groups, those from the bearded and those from the smooth heads. For each cross in each season, means with standard errors were computed for length of straw, length of head, kernels per head, and 1,000-kernel weight.

It was assumed that in these unselected hybrid populations, when such large numbers were employed, factors other than those correlated or closely associated with awns would introduce no serious error and that differences observed could therefore be attributed to the presence or absence of beards.

EXPERIMENTAL DATA AND DISCUSSION

Data are presented in Table 3 for each population in each of the 3 years. There were wide differences between seasons, although date of heading and ripening did not vary appreciably from June 1 and July 1, respectively. In 1932 there was a dry spring, dry weather at heading time, and scanty rainfall until nearly harvest time. In 1933 there was ample moisture during the spring vegetative period, with very dry weather from the middle of May to time of cutting. Pre-

TABLE 3.—*Data from bearded and beardless segregates.*

Cross	Year	N values		Length of straw, in.		Length of head, in.		Kernels per head		1,000-kernel weight grams	
		Bearded	Beardless	Bearded	Beardless	Bearded	Beardless	Bearded	Beardless	Bearded	Beardless
O. S. U. 63–19	1932	182	218	36.5±0.40	36.3±0.34	1.77±0.04	1.77±0.03	12.5±0.38	12.0±0.38	26.7±0.42	26.8±0.43
×	1933	207	213	46.6±0.26	45.8±0.28	2.07±0.03	2.04±0.03	16.9±0.39	17.8±0.38	32.8±0.27	31.1±0.28
Trumbull	1934	216	189	23.5±0.31	22.9±0.30	2.12±0.03	2.13±0.04	18.0±0.47	19.2±0.51	29.0±0.28	28.7±0.32
O. S. U. 168–10	1932	163	192	35.5±0.40	36.0±0.34	1.79±0.03	1.71±0.03	11.1±0.38	10.8±0.38	27.7±0.47	26.7±0.47
×	1933	90	167	46.7±0.36	46.6±0.30	2.06±0.05	2.07±0.04	16.1±0.51	18.4±0.40	32.2±0.33	32.5±0.24
Trumbull	1934	170	144	22.8±0.35	23.5±0.36	2.29±0.05	2.46±0.06	19.2±0.56	21.4±0.70	29.0±0.40	28.5±0.41
O. S. U. 101–3	1932	188	293	32.5±0.24	32.5±0.26	1.66±0.03	1.57±0.02	10.1±0.37	9.4±0.26	23.6±0.46	24.9±0.38
×	1933	236	423	41.6±0.24	42.2±0.18	1.73±0.03	1.75±0.02	16.1±0.35	16.9±0.24	29.6±0.23	29.0±0.19
Trumbull	1934	334	232	21.8±0.20	23.0±0.23	2.03±0.02	2.09±0.03	16.3±0.31	17.3±0.35	28.7±0.21	27.7±0.30
O. S. U. 101–3	1932	220	346	34.8±0.31	35.0±0.25	1.80±0.03	1.81±0.02	11.6±0.36	11.5±0.27	25.2±0.37	25.4±0.36
×	1933	215	134	44.9±0.28	44.2±0.38	2.14±0.03	2.12±0.04	17.9±0.34	17.5±0.49	31.3±0.30	30.3±0.45
Trumbull	1934	290	193	22.4±0.24	23.1±0.29	2.25±0.03	2.32±0.04	17.2±0.37	19.0±0.39	32.0±0.32	30.5±0.46
O. S. U. 63–8a	1932	253	260	32.1±0.30	32.6±0.30	1.71±0.03	1.70±0.03	13.3±0.36	13.0±0.33	25.4±0.28	26.2±0.28
×	1933	130	178	44.7±0.28	44.1±0.31	1.89±0.04	1.84±0.03	19.3±0.54	18.9±0.47	29.5±0.40	27.9±0.34
Trumbull	1934	231	189	24.0±0.30	24.0±0.34	2.17±0.04	2.33±0.04	19.6±0.51	21.9±0.62	29.4±0.30	28.1±0.35
O. S. U. 168–10	1932	103	245	35.0±0.50	35.8±0.35	1.75±0.04	1.80±0.03	12.2±0.55	13.9±0.37	27.4±0.60	28.7±0.44
×	1933	—	—	—	—	—	—	—	—	—	—
Trumbull	1934	—	—	—	—	—	—	—	—	—	—
Av. of means...		(3,228)	(3,616)	34.1	34.2	1.95	1.97	15.5	16.2	28.7	28.3
H. S. 205–3	1932	94	361	32.7±0.23	33.5±0.15	1.70±0.02	1.95±0.02	12.9±0.35	13.6±0.18	27.1±0.32	30.9±0.21
	1933	101	248	42.1±0.35	43.7±0.25	2.04±0.05	2.27±0.04	18.9±0.66	20.3±0.37	25.9±0.42	33.7±0.21
	1934	166	243	22.8±0.36	22.9±0.27	2.39±0.05	2.33±0.04	20.1±0.60	19.0±0.41	27.8±0.38	30.1±0.32
H. S. 495	1932	106	122	31.8±0.45	31.4±0.44	1.69±0.03	1.69±0.03	12.4±0.46	13.7±0.39	27.3±0.64	28.3±0.54
	1933	—	—	—	—	—	—	—	—	—	—
	1934	—	—	—	—	—	—	—	—	—	—
Grand av. of means......		(3,695)	(4,590)	33.7	34.0	1.95	1.99	15.6	16.3	28.4	28.8

cipitation in 1934 was not greatly different from that in 1932, but the average temperatures were decidedly higher from heading time to harvest

Straw growth was rank in 1933, intermediate in 1932, and poor in 1934. The shortest heads, however, were found in 1932, next longest in 1933, and longest in 1934. The number of kernels per head was closely associated with length of head and ranked the same between seasons with few exceptions. The weight of 1,000 kernels was low in 1932, whereas the differences between 1933 and 1934 were for the most part insignificant. In regular nursery trials, the standard variety Trumbull yielded 22.8 bushels in 1932, 38.3 bushels in 1933, and 36.1 bushels in 1934.

The selection H.S. 205-3, although segregating for awns, obviously is not suitable for this study. The marked differences between the bearded and beardless groups show that the latter contains superior lines. The data indicated that false conclusions might readily be drawn from too narrow a range of material. In this case the beardless group was the better and the awns therefore could not have been a contributing factor to the increased yield.

Among the bulk hybrids there was no significant difference between the bearded and beardless groups in length of straw. In two cases, however, the beardless groups had significantly longer heads. Both of these occurred in 1934.

Number of kernels per head is closely correlated with length of head (r values run +0.8 to +0.9 in nearly all cases), and therefore significant differences would be expected where differences in head length were found. This was actually the case, but in addition three other significant differences occurred and all five showed more kernels in the beardless groups. This definitely favors the awnless heads, but does not introduce an error of any great magnitude.

Considering the data as a whole, the evidence strongly suggests that there is no basis to assume that bearded segregates have any advantage in length of straw, length of head, or kernels per head. Neither does it indicate a serious bias in favor of the beardless group insofar as these measurements are concerned. Therefore, in the average weight of kernels must be reflected any increased yield, which in turn must be the result of better filling of the grain in awned heads.

Referring to the data on 1,000-kernel weight, in six cases again significant differences are found, and the bearded heads have the advantage in every instance. However, the differences are not large, and 5 times in 16 the beardless heads had actually heavier kernels. Taking the average of all means, the bearded heads led only by 0.4 gram per 1,000 kernels, or 1.41% over the beardless segregates.

Even if this figure is weighted somewhat in favor of the beardless heads because of the small positive correlation found between kernels per head and 1,000-kernel weight (in 1933 and 1934 the r values varied from about +0.30 to +0.45), the advantage is negligible from the practical point of view. Therefore, it is felt that bearded segregates may be largely dropped from the breeding nursery at the Ohio Experiment Station.

CORRELATIONS

With the data available it was felt worthwhile to work out the correlations among the four measurements made, since the extra labor involved was not excessive. Because of the large amount of tabular data included, a summary only is presented in Table 4. Agreement among the crosses was sufficiently close that the calculation of the average value was justified.

These average values were calculated according to the method outlined by Fisher (4) in example 33. Briefly the procedure was as follows: Convert r values to z, obtain the weighted mean of the z values, and reconvert to r. The standard errors were found from the formula $\frac{1-r^2}{\sqrt{\Sigma (n-3)}}$.

Certain expected correlations were clearly evident, namely, those among length of straw and head and kernels per head. The highest coefficients were obtained between kernels per head and length of head, the r values exceeding +0.900 in a number of individual cases. The remaining two correlations, namely, between length of straw and the other factors, were somewhat lower, but for nearly all cases exceeded +0.600.

The most interesting relationships were those involving the 1,000-kernel weight. In 1932 the r values were all very low, with a few negative coefficients in evidence. In 1933 and 1934 the positive association was quite definite, and although not very large, was highly significant mathematically. Highest correlations were found in 1934, and in that year the r values in many cases indicated an important interrelation.

Length of straw gave a higher correlation with 1,000-kernel weight than did either of the other measurements. The long tillers are the more vigorous, and this increased vigor is reflected in better filled grain. The coefficients considered together suggest that the increased yield of heads on long tillers results from the interaction of at least the three other factors studied. Further, the importance of each of these factors, especially the kernel size, varies with the season. Length of straw has a closer association with kernel size than has either length of head or kernels per head.

A very significant fact to be observed, especially evident in the data involving 1,000-kernel weight, is the seasonal variability in size of correlation coefficients. The data give some suggestion of variety-season interaction and indicate the complexity of the problem of determining yielding ability. They also emphasize the danger of placing too much reliability on associations, even of considerable magnitude, when drawn from the work of one or two seasons only.

THEORETICAL CONSIDERATIONS

As has been mentioned earlier, no attempt has been made in the work reported here to solve any of the basic problems involved. Investigators are not in good agreement, either as to the possible usefulness of beards to the wheat plant, or as to the means by which awns may influence yield. For various reasons, primarily because

TABLE 4.—*Summary of correlations from bearded vs. beardless wheat study.**

Year	Average of r values for correlation between					
	Length of straw and length of head	Length of straw and kernels per head	Length of straw and 1,000-kernel weight	Length of head and kernels per head	Length of head and 1,000-kernel weight	Kernels per head and 1,000-kernel weight
			Bearded Groups			
1932	+0.647±0.018	+0.592±0.020	+0.137±0.030	+0.809±0.010	+0.112±0.030	+0.050±0.030
1933	+0.671±0.019	+0.606±0.022	+0.494±0.026	+0.848±0.010	+0.420±0.028	+0.316±0.031
1934	+0.606±0.018	+0.620±0.018	+0.613±0.018	+0.877±0.007	+0.496±0.022	+0.441±0.023
Average	+0.639±0.010	+0.607±0.011	—	+0.848±0.005	—	—
			Beardless Groups			
1932	+0.558±0.018	+0.597±0.016	+0.106±0.025	+0.770±0.010	−0.004±0.026	+0.022±0.026
1933	+0.699±0.015	+0.692±0.016	+0.530±0.022	+0.867±0.007	+0.401±0.025	+0.348±0.026
1934	+0.633±0.020	+0.628±0.020	+0.594±0.021	+0.901±0.006	+0.504±0.024	+0.389±0.028
Average	+0.624±0.010	+0.636±0.010	—	+0.843±0.005	—	—
			Both Groups Together			
1932	+0.597±0.013	+0.595±0.013	+0.119±0.019	+0.787±0.007	+0.044±0.019	+0.033±0.019
1933	+0.686±0.012	+0.656±0.013	+0.514±0.017	+0.859±0.006	+0.405±0.019	+0.334±0.020
1934	+0.618±0.013	+0.624±0.013	+0.605±0.014	+0.888±0.005	+0.500±0.016	+0.419±0.018
			All Years			
Grand average	+0.631±0.007	+0.623±0.007	—	+0.846±0.003	—	—

*Data from bulk hybrid populations only.

the question is of little practical importance in Ohio, it is not proposed to carry these studies further. In the course of the work, however, certain possibilities presented themselves, and are recorded here for what they may be worth.

Two fundamental questions must be answered. These are: (a) What is the physiological function of the awn? (b) How is this function modified by the environment in which the crop is grown? It is in this environmental influence that the explanation for the apparent contradictions in the literature must be sought.

The extensive work of Schmid (10), Harlan and Anthony (6), Rosenquist (9), and others, give data which throw some light on the problem. Possibly overmuch emphasis has been placed on the high transpiration capacity of the awn, and the other more usual physiological functions. It is suggested that at the time the kernels are filling rapidly and translocation is very active, the awn may serve as a receptacle for substances, probably silicates in particular, which might plug up the conductive tissue or otherwise interfere with normal filling of the grain. If this should be true, the effectiveness of the beards would vary with the concentration of the soil solution in such substances as the silicates, and with the length of the filling period. Such an assumption fits in reasonably well with many observed facts and analyses and offers a possible line of attack.

SUMMARY

Farmers in Ohio object to bearded wheats, and there are practical reasons why beardless wheats are more desirable. Unless awns have a real capacity to increase yields, bearded segregates could be dropped from nursery plats with advantage.

Within any class of wheat, except white, there was a decrease in the proportion of bearded wheats grown in the United States from 1919 to 1929. Evidence concerning the value of awns presented by other investigators is contradictory and apparently the usefulness of beards is not the same in all locations.

In Ohio a study of 3,695 bearded and 4,590 beardless heads from eight segregating populations in three seasons indicated a probable slight increase in yield resulting from the presence of the awn. For practical purposes, however, the advantage was negligible, and there seems no reason for carrying bearded selections in the breeding nursery.

It is suggested on purely theoretical grounds that a function of the awn affecting yield may be its rôle in removing from the translocation system of the plant at filling time substances (possibly silicates, for example) which otherwise might interfere with the rapid movement of material into the grain.

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A COMPARISON OF GRAZING AND CLIPPING FOR DETERMINING THE RESPONSE OF PERMANENT PASTURES TO FERTILIZATION[1]

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A KNOWLEDGE of the relationship between the yields of permanent pastures as measured by grazing and by clipping is of fundamental importance in pasture research. Workers in various parts of the world have studied the effect of lime and fertilizer treatments on the yields obtained by clipping, yet it is possible that erroneous conclusions might be drawn from clipping experiments because the response of clipped plats may be quite different from that of grazed plats. Relatively little work has been done, however, on the effect of lime and fertilizer treatments on the yields of grazed plats. In fact the general use of grazing experiments to determine whether or not it would be practical to improve a pasture probably is not justified because of the difficulties and costs of such experiments and the limited area to which the results could be applied. It would be highly desirable, therefore, to know (a) the extent to which the results obtained from clipping experiments can be applied to grazing conditions, and (b) what system of clipping gives results most comparable to grazing.

The objective of the present investigation was to compare the responses of permanent pastures to fertilization as measured by (a) grazing with dairy cattle, (b) clipping permanent plats, and (c) clipping by the "difference-method", i.e., the difference between the yields of temporarily inclosed areas and corresponding grazed areas.

Since this paper deals primarily with a comparison of different methods of obtaining the yields of permanent pastures, a discussion of the economics of pasture improvement pertaining to this experiment will be left to a later paper.

EXPERIMENTAL PROCEDURE AND METHODS

The experimental area, located on a Monongahela fine sandy loam at Wardensville, West Virginia, consists of eight pastures having a total of 39 acres. In the spring of 1931 the pastures were plowed, given differential lime and fertilizer treatments in duplicate (Table 2), and sown with a mixture of Kentucky bluegrass, redtop, and white clover, using a nurse crop of oats. In order to compensate partially for differences in carrying capacity, the untreated pastures consisted of 6 acres each as compared with 4½ acres for the treated pastures.

During the 1932 season the pastures were grazed with registered Ayrshire cows. The total digestible nutrients supplied by the various pastures were cal-

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culated by allowing for maintenance, changes in body weight, amount of milk and butterfat produced, and the nutrients supplied by supplementary feed. The total digestible nutrients required for maintenance and for milk and butterfat production were calculated from data given by Henry and Morrison (4).[3] Allowance for changes in body weight was made in accordance with the recommendations of Knott, Hodgson, and Ellington (5).

Beginning with the 1933 season the pastures were grazed with registered Ayrshire heifers, mostly yearlings, that received no supplementary feed and, of course, produced no milk. Yields of total digestible nutrients from grazing were calculated from the data of Eckles and Gullickson (1) for the nutrient requirements of Holstein heifers for maintenance and growth (Table 1). The nutrient requirements of Holstein heifers, however, should be similar to those of Ayrshires.

The various pastures were grazed as uniformly as was possible without frequent changes in the number of cattle. Ordinarily there were three to seven animals on the better pastures and two to four on the poorer ones. The intensity of grazing was moderate to heavy. The weights of the cattle were recorded on two consecutive days corresponding with the dates of clipping. Additional weighings were made when cattle were added to or removed from a pasture between the dates of clipping.

TABLE 1.—*The nutrient requirements for normal growth of Holstein heifers.**

Weight of heifers, lbs.	Total digestible nutrients for maintenance, lbs. per day	Total digestible nutrients for 1 lb. of gain in weight, lbs.†
300	3.41	1.276
350	3.98	1.326
400	4.50	1.376
450	5.00	1.426
500	5.45	1.476
550	5.87	1.526
600	6.24	1.576
650	6.59	1.626
700	6.89	1.676
750	7.16	1.726
800	7.39	1.776
850	7.59	1.826
900	7.74	1.876
950	7.87	1.926
1,000	7.95	1.976

*From Eckles and Gullickson (1).
†Calculated by C. R. Enlow, formerly of the Bureau of Plant Industry, from the data of Eckles and Gullickson (1).

The yields of each pasture were also obtained by clipping nine permanent areas, each 4 feet square, that were distributed throughout the pasture and protected from grazing by means of wire cages (Fig. 1). The frequency of clipping depended upon the rate of growth, but ordinarily five or six clippings were made during the season. During 1932 the plats were clipped with a sickle, but since that time they have been clipped with a lawn mower set to cut at a height of 2 inches.

In addition to determining the yields by grazing and by clipping permanent plats, the yields were determined by the "difference-method" of clipping. With this method, nine additional cages were used in every pasture. At the beginning

[3]Figures in parenthesis refer to "Literature Cited", p. 359.

of the grazing season these cages were placed in representative areas throughout the pastures. In about three or four weeks these areas were clipped with a lawn mower set to cut at least as close as the pastures were grazed. At the same time clippings were made on nine corresponding areas that had not been protected from grazing. The difference between the yields of the plats that were protected

FIG. 1.—Pasture No. 4 on August 23, 1935, showing a permanent plat in the foreground and a "difference-method" plat in the background (Courtesy of R. F. Copple, Soil Conservation Service, U. S. D. A.)

from grazing and those that were grazed was assumed to represent the amount of forage eaten by the cattle. After each cutting the cages were of course moved to different areas.

The yields from clipping have been expressed in terms of total digestible nutrients, assuming 100 pounds of dry forage to contain 72 pounds of total digestible nutrients (6). The crude protein content of the clipped herbage was calculated from the total nitrogen content.

The statistical methods employed in the analysis of the data were those described by Ezekiel (2). Coefficients of simple correlation were calculated from formula 27 and corrected for the size of the sample by means of formula 25. When the value of n was large, the standard error of the correlation coefficient was calculated from formula 71.

EXPERIMENTAL RESULTS

Because of 3 years of dry weather (1932, 1934, and 1936), the average yield of the pastures during the 5-year period was relatively low. The yields of the untreated pastures, measured by grazing, averaged 759 pounds of total digestible nutrients per acre, and the increase in yields from the complete fertilizer and lime treatment was 110%.

Table 2 gives the relative yields of total digestible nutrients from

TABLE 2.—*Relative yields of total digestible nutrients from the clipped plats based on 100 for the yields from grazing.*

System of clipping	Relative yields of the different pasture plats*									Average (omitting plat 2)
	Plat 1 (P-L)	Plat 2 (None)	Plat 3 (P-K-L)	Plat 4 (N-P-K-L)	Plat 5 (P-L)	Plat 6 (None)	Plat 7 (P-K-L)	Plat 8 (N-P-K-L)	Average	
1932										
Permanent plats	160	150	177	153	149	133	127	152	150	150
"Difference-method"	157	161	133	137	132	132	113	126	136	133
1933										
Permanent plats	73	82	81	—‡	62	68	—‡	68	72	70
"Difference-method"	107	113	112	75	91	89	78	95	95	92
1934										
Permanent plats	66	89	60	77	64	67	58	68	69	66
"Difference-method"	101	110	126	147	122	127	135	148	127	129
1935										
Permanent plats	62	114†	52	72	64	67	55	81	71	65
"Difference-method"	137	199†	119	98	86	103	110	98	119	107
1936										
Permanent plats	56	97†	57	56	46	70	51	49	60	55
"Difference-method"	—	—	—	Not available		—	—	—	—	—

*L = Ground limestone in 1931 in amounts calculated to bring the soil to pH 6.5. P = 500 pounds per acre of 20% superphosphate in 1931 and again in 1933. K = 100 pounds per acre of muriate of potash in 1931 and again in 1933. N = 200 pounds per acre of nitrate of soda every year in two equal applications, one in early spring and one about the first of July.

†Clipped forage contained a high percentage of weeds.

‡Clipped yields not available because cages were overturned.

the two systems of clipping based on 100 for the yields from grazing. It will be noted, first, that the yields from clipping in 1932 are relatively high. Undoubtedly this was due partly to abnormal conditions. It was not possible to start grazing that year until May 20 (three weeks late), at which time there was a luxuriant growth of forage containing a high percentage of white clover. The yields of the clipped plats therefore were very high, whereas under grazing conditions part of the forage was trampled and not eaten. Moreover, as previously explained, dairy cows were used in 1932, and supplementary feed was fed. This complicates the calculation of total digestible nutrients supplied by the pasture and possibly introduces some errors. In fact, it should be recognized that regardless of the method of grazing employed, the yields are subject to certain experimental errors that undoubtedly explain some of the differences between the yields from grazing and from clipping.

The relative yields of the clipped plats in pasture No. 2 were much higher in 1935 and 1936 than in the other pastures. Undoubtedly this difference was due primarily to the high percentage of weeds, largely ox-eye daisy and field sorrel, which appeared in this pasture (Table 3). Not only were these weeds relatively unpalatable, but undoubtedly they were also much lower in nutritive value than the desirable pasture species

TABLE 3.—*Estimated botanical composition of the pastures in June, 1936.**

Pasture No.	Pasture treatment†	Bare space‡	Native grasses	White clover	Kentucky bluegrass	Red top	Weeds	$\frac{\text{Weeds}}{\text{Other sp.}} \times 100$
1	P-L	22	1	9	57	6	5	7
2	None	58	9	3	4	16	10	31
3	P-K-L	18	0	8	66	5	3	4
4	N-P-K-L	15	0	2	74	5	4	5
5	P-L	39	1	4	43	10	3	5
6	None	56	4	1	23	11	5	13
7	P-K-L	27	0	11	53	6	3	4
8	N-P-K-L	20	0	6	67	5	2	3

*Estimates for a given species are based on percentage of the total area occupied by that species
†See Table 2 for treatments.
‡In these estimates a pasture was considered to have no bare space only if the sod was of maximum density. Twenty per cent bare space, for example, represents a sod of 80% density

Except for pasture No. 2, the yields from clipping permanent plats gradually decreased in relation to the yields from grazing. The average yields of total digestible nutrients based on 100 for those from grazing were 150, 70, 66, 65, and 55, respectively, for 1932, 1933, 1934, 1935, and 1936. As explained previously, the high value obtained in 1932 is believed to be due to the abnormal management that year. Undoubtedly this decrease was due partly to the fact that the grazed portions of the pastures received the manure from the droppings, whereas the clipped areas did not. Moreover, except for the first two years there has been consistently more clover in the grazed pastures than in the clipped plats, as shown in Table 4. Since the clipping treatment has been less favorable to the development of

TABLE 4.—*Estimated percentages of white clover in the pastures and in the permanent clipped areas*

Pasture number and treatment*	Management	1932 June†	1933		1934		1935		1936 June	Average 1934–36
			June†	September	May	October	June	September		
1 (P L)	Grazed	—	—	5	7	4	23	8	9	10
	Clipped	24	2	3	4	1	7	3	5	4
2 (None)	Grazed	—	—	1	1	1	3	2	3	2
	Clipped	15	trace	1	1	trace	1	1	1	1
3 (P K L)	Grazed	—	—	12	33	4	23	15	8	17
	Clipped	41	1	10	19	3	13	5	4	9
4 (N-P K L)	Grazed	—	—	7	9	4	13	4	2	6
	Clipped	36	2	8	14	3	10	2	2	6
5 (P L)	Grazed	—	—	1	2	2	8	3	4	4
	Clipped	16	1	1	3	1	2	2	1	2
6 (None)	Grazed	—	—	2	3	3	12	1	1	4
	Clipped	35	trace	1	1	1	3	trace	trace	1
7 (P-K-L)	Grazed	—	—	7	17	4	24	7	11	13
	Clipped	47	1	8	15	2	7	6	3	7
8 (N-P-K L)	Grazed	—	—	3	5	4	12	3	6	6
	Clipped	54	1	3	2	1	4	2	2	2
Average	Grazed	—	—	4.7	9.6	3.2	14.7	5.4	5.5	7.7
	Clipped	—	—	4.4	7.4	1.5	5.9	2.6	2.2	3.9

*See Table 2 for treatments

†At the beginning of the experiment there was no apparent difference between the botanical composition of the grazed and the clipped areas and consequently botanical estimates were not made on both areas

white clover than has grazing, it would be expected that the yields from clipping would tend to become relatively lower, especially in the pastures containing a high percentage of clover. The studies have not been conducted long enough, however, to enable satisfactory comparisons of the relative yields from clipping and from grazing in relation to the amounts of white clover.

In spite of the difference during different years between the yields from clipping and from grazing, there has been a high correlation during any one year between the yields from grazing and from clipping permanent plats (Table 5). In 1932, for example, the square of .919, or 84% of the variations in the yields as measured by grazing, is associated with similar variations in the yields of the clipped plats. Thus it appears that, although the yields obtained by clipping permanent plats cannot be converted directly into yields in terms of grazing units, they have been a very effective measure of the relative increases in yields resulting from various lime and fertilizer treatments.

TABLE 5.—*Coefficient of correlation between the yields of the pastures as measured by grazing and by clipping permanent plats.*

Year	Number of comparisons (n)	Coefficient of correlation (r)
1932	8	.919
1933	6	.921
1934	8	.898
1935	8	793
1936	8	.715
1935*	7	.842
1936*	7	.937

*Omitting pasture No. 2, which contained a high percentage of weeds in the clipped forage.

The crude protein content of the clipped herbage from the poorest or untreated plat ranged from 12.6 to 15.4% during different years with an average of 13.7%. On the best plat the range was from 14.3 to 20.1% with an average of 17.4%. Differences in the crude protein content of the clipped herbage, however, apparently were not a factor in determining the relationship between the yields from grazing and from clipping permanet plats.

In contrast to the results obtained by clipping permanent plats, the yields from clipping by the "difference-method" did not show a progressive decrease in relation to the yields from grazing. As shown in Table 2, the relative yields from clipping by the "difference-method" were 136, 95, 127, and 119, respectively, for 1932, 1933, 1934, and 1935.

The yields of total digestible nutrients calculated from the "difference-method," therefore, average 19% higher than those obtained by grazing. Undoubtedly this difference is due, at least partly, to the energy expended in grazing. Moreover, since the grass outside the cages is grazed repeatedly, it probably does not make as much total growth as does grass in the protected areas under the cages.

The data given in Table 6 show a consistently high correlation be-

tween the yields from grazing and from the "difference-method" of clipping. Thus, in 1932, the square of .926, or 86% of the variations in the yields obtained by grazing, is associated with similar variations in the yields as measured by the "difference-method" of clipping. What is even more significant is the high coefficient of correlation (.860 ± .025) for the 4-year period between the yields of the individual clippings in the various pastures and the corresponding yields from grazing. This relationship (Fig. 2) shows that the "difference-method" of clipping has given a good measure of the yields obtained by grazing with dairy cattle.

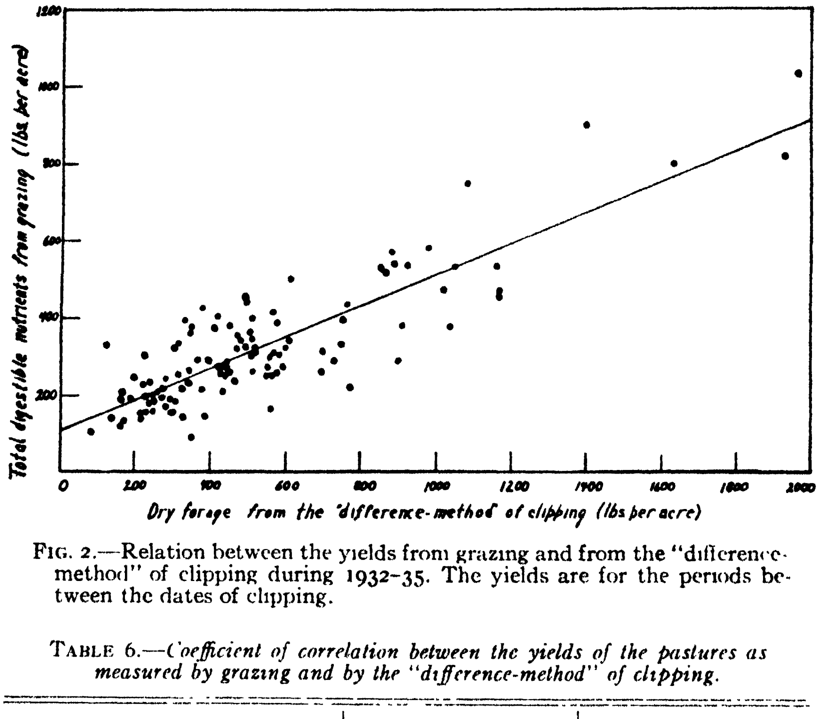

FIG. 2.—Relation between the yields from grazing and from the "difference-method" of clipping during 1932–35. The yields are for the periods between the dates of clipping.

TABLE 6.—*Coefficient of correlation between the yields of the pastures as measured by grazing and by the "difference-method" of clipping.*

Year	Number of comparisons (n)	Coefficient of correlation (r)
1932	8	.926
1933	8	.915
1934	8	.965
1935	8	.898
1932–35	32	.855
1932–35 (based on periods between dates of clippings)	108	.860 ± .025

As in the case of the permanent plats, differences in the crude protein content of the clipped herbage apparently were not a factor in determining the relationship between the yields from grazing and from the "difference-method" of clipping.

DISCUSSION

The data presented in this paper show that, except for the pasture containing a high percentage of weeds, there has been a progressive decrease in the relative yields from clipping permanent plats as compared with yields from grazing. The average yields of total digestible nutrients from clipping, based on 100 for those from grazing, were 150, 70, 66, 65, and 55, respectively, for the first, second, third, fourth, and fifth years. As explained previously, the high value of 150 obtained during the first year is believed to be due largely to the abnormal management that year. The data of Gardner, et al. (3), when expressed on the same basis, show an average relative yield of 136 from clipping small plats that were relocated every two or three years. The relative yields, therefore, should be comparable to those obtained during the first two or three years from the permanent plats in the present investigation, yet they average considerably higher. This difference may be due to the fact that in this investigation a system of rather close continuous grazing was followed, whereas Gardner and his associates employed rotational grazing and possibly pastured less closely. These differences emphasize the need of further studies of the effect of management of both grazed and clipped plats, especially since the botanical composition and the yields of clipped plats are known to vary markedly with the height and frequency of clipping.

The promising feature of the results obtained by clipping permanent plats, however, is that except for the pasture containing a large amount of coarse weeds, the clipped yields gave a good measure of the percentage response to the various treatments obtained by grazing. This has already been shown in Tables 2 and 5 but is further emphasized in Table 7. Thus the average percentage increase in yield from the complete fertilizer and lime treatment was 111 when obtained by grazing and 99 when obtained by clipping permanent plats. If such a relationship between the yields from the two methods is found to hold quite generally under different pasture conditions, it would mean that much more weight could be given to experimental results obtained by clipping permanent plats. Before the clipped yields could be interpreted in terms of grazing units, however, it

TABLE 7.—*The percentage increase in yields from the complete fertilizer and lime treatment as measured by grazing and by clipping permanent plats.**

Year	Measured by clipping permanent plats	Measured by grazing
1932	104	90
1933	70	90
1934	96	110
1935	132	104
1936	93	159
Average	99	111

*The untreated pasture that contained a large amount of coarse weeds in 1935 and 1936 was not used in the comparisons for those two years. Thus the percentage increases for those years are based on the yields of only one untreated pasture.

would be necessary to know the carrying capacity of the untreated pastures.

Unfortunately, many pastures are so variable that a knowledge of the carrying capacity of the pasture as a whole would be entirely inadequate for obtaining the carrying capacity of a particular part of the pasture. In many clipping experiments, therefore, it is not practical to determine the carrying capacity of the untreated area by means of grazing, and consequently some system of clipping that would give yields directly convertible into animal units would be very desirable. Regardless of the system employed, it is obvious that because of seasonal variations, several years would be required in order to obtain a reliable average yield. The "difference-method" of clipping apparently could be used for this purpose, but as is pointed out later, a simpler system of clipping would be more desirable. The use of permanent plats, as previously explained, is not suitable because of the differential cumulative effect of clipping as compared with grazing. It should be possible, however, to establish a definite relationship between the yields from grazing and from a standard system of clipping plats that are relocated every year. The possibilities of this method are now being investigated.

From these considerations it seems evident (a) that, except in pastures containing a considerable quantity of unpalatable species, the percentage increase in yields due to lime and fertilizer treatments can be obtained by clipping permanent plats, and (b) that the carrying capacity of the untreated area can be determined by grazing, by the "difference-method" of clipping, or possibly by clipping plats that are relocated every year. With this information the response of a pasture to lime and fertilizer treatments could readily be expressed in terms of grazing units.

If, on the other hand, the response of a pasture to lime and fertilizer treatments is determined by the "difference-method" of clipping, it appears from the data obtained in this investigation that the yields can be converted directly into yields in terms of grazing units. Theoretically it should not be necessary to have fences between plats; actually, however, fences may be necessary to prevent overgrazing on the treated areas and undergrazing on the poorer areas. An additional factor to consider is that if the pasture is not smooth the cattle can graze much closer than it is possible to clip with a lawn mower. From a practical standpoint, therefore, the "difference-method" involves more expense for equipment, requires more labor, and must be more carefully supervised than a clipping experiment with permanent plats, and consequently may not be justified except when a small number of treatments are to be compared or as a check against more simple methods of clipping.

SUMMARY

The response of pastures to fertilizer and lime treatments as measured by grazing has been compared with the response as measured (a) by clipping permanent plats and (b) clipping by the "difference-method", i. e., obtaining the difference between the yields of temporarily inclosed areas and corresponding grazed areas.

Although the yields obtained by clipping permanent plats have shown a progressive decrease in relation to the yields obtained by grazing, there has been a high correlation in any one year between the yields from clipping and the yields from grazing. A method is suggested whereby the clipped yields can be expressed in terms of grazing units.

The response to fertilizer and lime treatments determined by the "difference-method" of clipping was a good measure of the response obtained by grazing. The ratio between the weight of oven-dry forage obtained by this method and total digestible nutrients calculated from grazing was 1:0.61.

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THE RELATION OF ORGANIC MATTER AND FERTILIZER TO THE GROWTH AND COMPOSITION OF RICE[1]

M. B. STURGIS AND J. FIELDING REED[2]

THERE has been much experimental work on the quality and composition of crops as affected by soil conditions and by various treatments. In parts of the world where it is an important crop, rice has had its share of investigational work of this type. Copeland (2)[3] gave a detailed review of the literature on this subject prior to 1924. More recent work has been carried on by Kapp (4, 5, 6) and others at the Rice Branch Station in Arkansas. Kapp found that the studies of the composition of the rice plant afforded data of considerable value in an understanding of the effects of fertilizers and of the reaction of plants to their application.

In studying the coastal prairie soils of the Southwest, it was found (8) that some very definite changes had developed in the soils as a result of growing irrigated rice for many years. Through the effects of cropping the soil, colloids have become deflocculated, the alkalinity of the soils has increased, and large amounts of colloidal iron and silica have accumulated. Also, the nitrogen contents of the soils have been depleted to less than half their original values, and the amounts of soluble and readily available phosphorus have been reduced to extremely low values. Since not only the low yields, but also the poor quality of the rice from some few localities in Louisiana are thought to be associated with peculiar soil conditions, it is evident that a study of the relation of some of the more widely occurring soil abnormalities to the growth and composition of rice would be of both practical and scientific interest. The purpose of this preliminary investigation has been to determine the relation of the composition of rice, especially the nitrogen and ash constituents, to the soil conditions as they occur before cropping and also after long-continued cropping with and without certain treatments.

EXPERIMENTAL

The soils used in the investigations were a deflocculated Crowley silt loam which had been cropped alternately to rice for 40 years at the Rice Experiment Station at Crowley, Louisiana, and a virgin Crowley silt loam from an adjacent area. The older cultivated soil was particularly low in available nitrogen and phosphorus. It contained large amounts of soluble and colloidal silica and had increased in alkalinity from long-continued cropping to flooded rice. The virgin soil was in excellent physical condition and had approximately three times the productive capacity of the old cultivated soil (8).

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[3]Figures in parentheses refer to "Literature Cited", p. 366.

Soil material from the surface horizon of these soil areas was passed through a sieve of ¼ inch mesh, thoroughly mixed, and then 9-kilogram portions of the soil material were placed in 3-gallon stoneware pots. The deflocculated soil contained in the pots was given treatments of ground soybean plants, nitrogen, phosphorus, potassium, calcium, and sulfur as indicated in Table 1. Duplicates of both the old and the virgin soils were left untreated and used as checks as to the effects of the treatments and as a means of determining the effects cropping and flooding had made on the old soil. After the treatments had been applied and mixed with the soil, the soil was made up to optimum moisture and planted to Blue Rose rice on April 21, 1933.

The rice was flooded with distilled water 3 weeks after emergence and kept flooded until mature. The pots were kept under controlled conditions in the field and exposed to normal rain and sunshine. Distilled water was used as a supplement to rain in order to keep 3 inches or more of water on top of the soil The rice was grown to maturity, harvested, and air-dried. Yields of heads and straw were determined and are given in Table 1.

The heads, which included the whole panicles, and the straw, which included the leaves and stem from 1 inch above the surface of the soil to the base of the panicles, from each pot were finely ground with a Wiley mill, thoroughly mixed, and analyzed. Analyses were made of the heads and of the straw from each pot. The results as reported are the averages of duplicate determinations from duplicated treatments. The methods of analysis used were those recommended by the A. O. A. C. (7), with the exception of nitrogen which was determined by the Kjeldahl method modified to use copper selenite as a catalyst (1).

EXPERIMENTAL RESULTS

The results given in Table 1 show the effects that the additions of leguminous organic matter, fertilizer salts, lime, and sulfur have had upon the yield of rice on deflocculated Crowley silt loam soil under controlled conditions. It was observed that the head yield on the virgin Crowley silt loam soil was approximately three times that for the deflocculated soil. The additions of organic matter in the form of soybeans gave a marked increase in the yields on the deflocculated soil. The addition of nitrogen in the form of ammonium sulfate gave an increase, but its use was less effective than the addition of soybeans. The use of the phosphate with soybeans was the most effective treatment in increasing the yield of rice. The phosphate when used with ammonium sulfate was much less effective than when applied with soybeans. The use of the potassium salt had relatively less effect in increasing the yield of rice than did the application of the phosphate. The improvement was not significant from either the application of potassium sulfate with soybeans and phosphate or with the complete commercial mixture. Where lime was added in treatments including organic matter, the yields were increased except in the treatments including phosphate in which cases the yields were decreased. The addition of lime decreased the ratio of grain to straw except where potassium was added in the treatment. Sulfur in combinations with the commercial fertilizer materials increased the yields, but it also decreased the ratio of grain to straw except in the case of the complete fertilizer. Sulfur when used with soybeans depressed the yield of heads but increased markedly the yield of straw.

TABLE 1.—*The effects of additions of leguminous organic matter, fertilizer salts, lime, and sulfur on the yield of rice on deflocculated Crowley silt loam under controlled conditions.*

Sample No.	Treatment	Yield in grams per pot		
		Heads	Straw	Total
1	Check, no treatment	8.8	18.7	27.5
2	0.05% soybeans	12.3	34.9	47.2
3	0.05% soybeans and 0.05% $CaCO_3$	13.2	45.2	58.4
4	0.05% soybeans and 0.003% P as $CaH_4(PO_4)_2.H_2O$	22.9	42.3	64.2
5	0.05% soybeans, 0.003% P amd 0.05% $CaCO_3$	19.4	50.1	69.5
6	0.05% soybeans and 0.01% K as K_2SO_4	17.7	45.4	63.1
7	0.05% soybeans, 0.01% K and 0.05% $CaCO_3$	19.5	36.2	55.7
8	0.05% soybeans, 0.003% P and 0.01% K	23.0	42.3	65.3
9	0.05% soybeans, 0.003% P, 0.01% K and 0.05% $CaCO_3$	22.7	44.4	67.1
10	0.0034% N as $(NH_4)_2SO_4$	10.2	19.2	29.4
11	0.0034% N and 0.003% P as $CaH_4(PO_4)_2.H_2O$	11.9	23.0	34.9
12	0.0034% N and 0.01% K	9.9	18.9	28.8
13	0.0034% N, 0.003% P, and 0.01% K	10.6	21.4	32.0
15	0.0034% N, 0.003% P, and 0.04% S	17.9	35.9	53.8
16	0.05% soybeans, 0.003% P, and 0.04% S	13.1	59.1	72.2
18	0.0034% N, 0.003% P, 0.01% K, and 0.04% S	18.2	34.7	52.9
2W	Virgin Crowley silt loam, no treatment	25.7	49.7	75.4

Previous studies (8) on the available nutrients, degree of base saturation, and reaction in the deflocculated Crowley silt loam and in the virgin Crowley silt loam had shown that the nitrogen content of the virgin soils was 0.201%, while that of the deflocculated soil was 0.080%. At the beginning of these culture studies the pH of the virgin soil was 6.0 and that of the deflocculated soil 7.1. The easily available phosphorus in the virgin soil was 12.5 p.p.m. as compared with 4.5 p.p.m. in the deflocculated soil. Exchangeable potassium in the virgin and deflocculated soils was 100 and 61 p.p.m., respectively. Analyses of the soil solution from the deflocculated soil in pots taken at intervals during the growth of the rice after flooding showed that the soluble manganese varied from 8 to 14 p.p.m., but there seemed to be no definite relationship between soluble manganese and treatment. The soluble aluminum varied from 0.8 to 1.2 p.p.m. under the various treatments. The concentration of iron in the soil solution was relatively high and varied from 1.2 to 26.0 p.p.m. The addition of the organic matter increased the solubility of the iron. In all cases the soluble phosphorus in the soil solution was low, 0.03 p.p.m. or less. The soil solution of the deflocculated soil under all treatments was high in soluble silica or silicates and varied in concentration from 21 to 30 p.p.m. as SiO_2. These values for soluble silica are probably too low, since a double filtration through a pressure filter was used in order to be as sure as possible that only soluble silica was being determined.

The results given in Table 2 show that the addition of nitrogen both in the form of soybeans and as ammonium sulfate increased the percentage and the total amount of nitrogen in the rice heads except in the case where sulfur was added with soybeans and phosphate. It has been pointed out that sulfur in this treatment depressed the yield of heads. One of the most noticeable variations shown by the analyses is the much greater percentage of nitrogen, 40% more, found in the heads of rice grown on the virgin soil than that found in the heads from the untreated deflocculated soil. The percentages of ash and silica in the heads varied considerably, and approximately four-fifths of the ash consisted of silica. It is obvious that the addition of sulfur as free sulfur depressed the percentages of ash and silica in the heads. One of the most evident observations made during the course of the work is the fact that the plants, both heads and straw, grown on the deflocculated soil were higher in silica than those grown on the virgin soil.

TABLE 2.—*The effects of the additions of leguminous organic matter, fertilizer salts, lime, and sulfur on the nitrogen content, ash, and mineral constituents in the heads of rice grown on deflocculated and virgin Crowley silt loam.**

Sample No.†	H_2O %	N %	Ash %	SiO_2 %	P_2O_5 %	SO_3 %	CaO %	MgO %	Fe_2O_3 %
1	8.27	0.883	8.29	7.82	0.377	0.409	0.171	0.080	0.043
2	8.37	0.981	9.85	7.90	0.388	0.436	0.146	0.065	0.041
3	8.76	0.997	10.00	8.64	0.398	0.466	0.135	0.085	0.040
4	10.02	0.956	7.50	5.61	0.477	0.444	0.128	0.115	0.035
5	9.45	1.015	8.22	5.69	0.550	0.441	0.145	0.095	0.035
6	9.17	1.013	7.70	6.13	0.376	0.555	0.115	0.070	0.040
7	9.20	0.981	8.05	6.71	0.376	0.524	0.130	0.115	0.035
8	10.75	0.913	6.17	6.13	0.550	0.448	0.145	0.150	0.026
9	8.95	0.945	6.78	5.36	0.447	0.445	0.175	0.160	0.040
10	9.02	0.989	7.96	6.17	0.511	0.522	0.155	0.090	0.035
11	9.22	0.964	7.58	7.74	0.511	0.523	0.145	0.160	0.030
12	9.02	0.967	7.40	5.46	0.550	0.604	0.150	0.235	0.030
13	9.70	0.974	7.84	6.53	0.596	0.494	0.135	0.145	0.045
15	10.25	0.902	6.11	5.77	0.511	0.557	0.120	0.120	0.045
16	2.75	0.844	6.80	5.39	0.477	0.493	0.140	0.185	0.045
18	9.85	0.888	6.06	4.53	0.511	0.554	0.125	0.220	0.050
2W	9.61	1.22	5.00	3.78	0.447	0.648	0.156	0.265	0.040

*The determinations of moisture are on the basis of the air-dry sample. The other determinations are on the basis of oven-dry weight.
†See Table 1 for treatments.

The data in Table 2 show that the percentage of phosphorus is higher in the heads of rice from those treatments where phosphate had been added; however, the addition of phosphate was more effective in increasing the yields than in raising the percentage composition.

All of the treatments added to the deflocculated soil contained sulfur in one or more forms and increased the percentage of sulfur in the heads. The greatest percentage of sulfur was found in the heads of rice grown on the virgin soil. The virgin soil was relatively high in sulfur, 0.245% reported as sulfur trioxide (8).

The percentage composition of the rice heads from the different treatments showed variations in the calcium and magnesium contents,

but no definite relationship could be established. The heads from the virgin soil were relatively high in magnesium.

Data in Table 3 show that the nitrogen content of the straw was only about one-third that of the heads and that there was no significance in the nitrogen content of the straw as affected by treatments on the deflocculated soil. The nitrogen content of the straw from the virgin soil was relatively high.

TABLE 3.—*The effects of the additions of leguminous organic matter, fertilizer salts, lime, and sulfur on the nitrogen content, ash, and mineral constituents in the straw of rice grown on deflocculated and virgin Crowley silt loam.**

Sample No.†	H_2O %	N %	Ash %	SiO_2 %	P_2O_5 %	SO_3 %	CaO %	MgO %	Fe_2O_3 %
1	7.25	0.347	14.61	14.82	0.217	0.225	0.435	0.315	0.075
2	7.75	0.482	15.47	12.47	0.217	0.275	0.515	0.170	0.091
3	7.35	0.373	15.11	12.06	0.194	0.275	0.535	0.240	0.068
4	7.50	0.309	17.12	13.88	0.159	0.225	0.500	0.185	0.083
5	7.80	0.309	15.63	13.07	0.170	0.295	0.420	0.180	0.094
6	7.83	0.407	16.33	13.54	0.205	0.355	0.465	0.195	0.089
7	7.26	0.418	17.93	15.47	0.205	0.267	0.495	0.170	0.063
8	7.42	0.298	16.91	13.19	0.298	0.255	0.475	0.155	0.069
9	7.02	0.363	17.38	15.94	0.170	0.230	0.270	0.125	0.099
10	7.20	0.451	15.60	13.53	0.217	0.350	0.490	0.080	0.071
11	7.50	0.319	16.83	14.19	0.266	0.375	0.540	0.190	0.095
12	7.70	0.434	16.32	13.11	0.217	0.350	0.444	0.290	0.075
13	7.65	0.261	16.91	13.30	0.217	0.380	0.490	0.195	0.075
15	7.32	0.362	14.62	12.07	0.256	0.375	0.673	0.175	0.060
16	7.60	0.343	13.59	10.66	0.243	0.375	0.541	0.130	0.075
18	7.20	0.332	13.78	11.34	0.243	0.300	0.550	0.255	0.090
2W	6.31	0.454	9.80	7.55	0.128	0.350	0.575	0.485	0.090

*The determinations of moisture are on the basis of the air-dry sample. The other determinations are on the basis of oven-dry weight.

†See Table 1 for treatments.

The ash and silica contents of the straw were much higher than those of the heads. The ash and silica contents of the straw from the virgin soil were much lower than those from the deflocculated soil. Although silica was absorbed in large amounts by the rice on the deflocculated soil, there was no definite relationship between the amount found in the straw and treatment.

Both phosphorus and sulfur were much lower in the straw than in the heads. It is interesting to note that the phosphorus content of straw from the virgin soil was low, while the phosphorus content of the heads was relatively higher.

The calcium and magnesium contents of the straw were much higher than those of the heads. The magnesium content of the straw from the virgin soil was very much greater than that from any treatment on the deflocculated soil.

The data show that there was a variation in the percentage of iron in the straw from the different treatments, but apparently no relation existed between treatment and iron. In all cases the content of iron was high. The percentage of iron in the straw was much higher than it was in the heads.

DISCUSSION

An examination of the data shows that rice growing on the deflocculated soil was affected not only by the lack of nutrients, particularly nitrogen and phosphorus, but it was probably also depressed by other peculiar conditions which had developed in the soil. One of these was the occurrence of high amounts of soluble silica. Whether the presence of large amounts of soluble silica was the result of an increased hydrolysis of the primary silicates from the influence of irrigation is not yet definitely known. The high soluble silica content in the soil was associated with high silica content in the plant (Tables 2 and 3). The yields indicated that silicon was not substituted for phosphorus in the plant nutrition.

It can be seen from the data presented in Tables 1, 2, and 3 that the addition of nitrogen to the soil increased the yield of rice heads and the percentage of nitrogen in the heads. Where sulfur was added in the presence of active nitrogenous organic matter, the yield of heads and the percentage of nitrogen in the heads were depressed. Possibly the reduced compounds of sulfur, produced through the effects of anaerobic decomposition of the soybeans, were responsible for this depression. The relatively large amount of nitrogen in the virgin soil was associated with a high nitrogen content in the rice heads.

The addition of phosphorus to the highly deficient deflocculated soil and the presence of relatively larger amounts of phosphorus in the virgin soil were reflected by increases in the yield of rice and in the percentage of phosphorus in the heads. Addition of potassium sulfate showed relatively little effect when added with phosphates on the increase in yield of rice. Apparently the potassium did exert an influence in balancing the effects of excess lime and sulfur in their tendencies to cause the production of an abnormal proportion of straw.

Large amounts of magnesium were found in the rice plants grown on the virgin soil. The straw was particularly high in its magnesium content and low in phosphorus content. The heads were relatively high in phosphorus content and lower in magnesium. The soils in all cases were high in available magnesium (8). These observations as set forth indicate that, contrary to a rather prevalent belief, the absorption of phosphorus by the rice plant and its translocation within the plant were not necessarily directly associated with the absorption and the movement of magnesium.

Considerable mention of the high iron requirement of rice can be found in the literature (3, 4, and 5). The results from analyses presented show that the iron content of both heads and straw was high in all cases. The percentage of iron in the straw was roughly twice that found in the heads. The soil solution of the deflocculated soil was high in soluble iron. A test on the soil solution of the flooded virgin soil while it was planted to rice indicated that it was also high in soluble iron. From studies on reduced products in the soil, it had been found that the soluble iron in flooded rice soils occurred largely in the ferrous state and most likely as ferrous carbonate (8). The only condition under which rice could suffer from a lack of iron

in flooded soils would be that the plant could not absorb the ferrous iron. The data from the cases studied show that large amounts of iron were absorbed by the rice plant. On the other hand, it appeared that the plants could not exclude the iron and actually absorbed more than was needed. As to the physiological function and the forms in which the iron occurred in the rice plants, the authors did not investigate.

SUMMARY

A study was made of the relation of additions of nitrogenous organic matter, fertilizer salts, lime, and sulfur to the yield, protein, and ash constituents of rice grown in Crowley soils.

The addition of nitrogen to a deflocculated Crowley silt loam increased the percentage of protein in the rice heads and the yield of rice grown on the soil. A relatively large amount of nitrogen in a virgin Crowley soil was found to be associated with a high protein content in the rice.

The application of phosphorus to a soil deficient in this nutrient resulted in a greater yield of rice and a higher phosphorus content on the percentage basis. The comparatively higher amount of phosphorus in a virgin Crowley silt loam was reflected by a higher yield of rice and a high percentage of phosphorus in the rice heads.

The use of potassium salts as a fertilizer seemed to balance the effects of excess amounts of lime and sulfur in their tendencies to cause the development of a low ratio of grain to straw.

The indications are that the absorption and translocation of phosphorus by the rice plant were not necessarily dependent upon the absorption and movement of magnesium.

Rice grown on alkaline soil which contained large amounts of soluble and colloidal silica absorbed unusually large amounts of silica. The silica content of the straw was much higher than that of the heads. Silicon was not substituted for phosphorus as a nutrient in the growth of rice.

The iron content of both heads and straw was found to be high in all cases observed. The soil solution of the flooded soil was high in soluble iron which existed largely in the ferrous state.

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DISTRIBUTION OF RESIDUAL SOIL MOISTURE AND NITRATES IN RELATION TO THE BORDER EFFECT OF CORN AND SORGO[1]

JOHN P. CONRAD[2]

THE enhanced growth of plants in rows bordering on uncropped areas is unquestionably caused by one or more of the following reasons: The additional sunlight, the additional soil moisture, or the additional supply of plant nutrients placed at their disposal. The question of "border effect" has been previously studied largely from the point of view of field plat technic. The Committee on Standardization of Field Experiments of the American Society of Agronomy (1)[3] has recommended procedures in the field which will largely obviate errors in yield, etc., which might arise from this source. Various citations in its bibliographies give evidence of the extent and amount of border effect with various crops under a wide range of environmental conditions. In this paper, besides the utilization of additional sunlight as shown by the greater yield from the border plants, data were collected showing the utilization of additional soil moisture and plant nutrients which were at the disposal of the border plants. A survey of the residual soil moisture and nitrate conditions at or near crop maturity was made by taking series of samplings from planes in the soil perpendicular to the crop-fallow boundary lines for the two crops, sorgo and corn.

CULTURE OF THE CROPS

An area previously planted in 1934 to a crop of irrigated tobacco and free from morning glory (*Convolvulus arvensis*), except for a few small patches, was selected for these experiments. Honey sorgo and King Philip Hybrid corn (Cf. Smith (8) for a description) were planted in blocks interspersed with fallow strips 30 feet wide. Each block containing four rows planted 3.5 feet apart was about 60 feet long. As poor stands resulted from the first planting the blocks were replanted on May 16, 1935, and thinned on June 7 to a stand of approximately 6 inches in the row for the sorgo and 10 to 12 inches for the corn. The area was irrigated on June 8 to resettle the soil about the roots and not irrigated again during the remainder of the growing season. Though this irrigation resupplied the soil to its field capacity, it is believed the amount of moisture which had been used by these seedling plants up to June 8 would be almost insignificant compared with the total amount used during the season. No rain fell during the period of the experiment except 1.03 inches distributed in three storms between Oct. 2 and Oct. 15, 1935. Except for these storms which affected only the surface foot of soil and then not materially, the conditions were very nearly ideal for studies of this kind. At the time of harvest, Oct. 25, 1935, the seeds of the sorgo had just reached maturity

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Many of the determinations and calculations reported herein were performed by Mr. I. I. Cornet, laboratory technician. Received for publication February 8, 1937.

[2]Associate Agronomist in the Experiment Station.

[3]Reference by number is to "Literature Cited", p. 378.

while the plants were green in color. The corn, on the other hand, had been ripe for nearly a month, the plants standing brown and dry.

The rows were harvested individually, the total green weight being secured and a sample consisting of several plants was dried at about 60°C to determine the dry weight. It is probable that the drying out of water from the plant tissues was incomplete at this temperature especially so with the sorgo plants as they contain considerable percentages of sugar. Direct comparisons of "dry matter produced" between corn and sorgo in these experiments cannot therefore be made. The yields of dried material thus determined for 100 feet of row were computed and the results summarized in Table 1. The evidence of a border effect under the conditions of these experiments is thereby established statistically. In Tables 2 to 5, inclusive, the yields of the individual rows involved in the soil samplings are given, rather than the averages for the experimental area as a whole as given in Table 1.

TABLE 1.—*Evidence of border effect under the conditions of these experiments.**

	Corn	Sorgo	Sorgo adjoining†
Pairs of rows involved	4	4	10
Yields: Border rows	47.5	141.9	166.6
Inner rows	33.4	102.7	106.6
Difference	14.1	39.2	60.0
Student's odds (7)	39:1	78:1	>10,000:1

*Yields are given in pounds of dried material for 100 feet of row.

†These plats (not involved in the samplings of the soil as reported hereinafter) were handled as nearly like the others as possible except that the rows were run north and south.

FIELD AND LABORATORY PROCEDURE

Soil samples were taken with a set of sampling tubes described by Veihmeyer (9). In connection with the samples for moisture contents and moisture equivalents only single ones were taken for each foot depth as reported in Tables 2 and 3. Samples for nitrates represented composites of six from the 0- to 4-inch depth, three from the 4- to 12-inch depth, and two from each lower foot-depth down to and including the seventh foot. Single samples were taken for each foot depth below 7 feet.

Samples for moisture and nitrates were made at various times during the growing season, but only those are included in this paper which would most closely reflect the total withdrawals by the plants. These include the soil sampling across the corn-fallow boundary in the middle of September when the corn was in the hard dough to ripe stage, and the sampling across the sorgo-fallow boundary a few days after the harvest in late October. All samples were taken at least 20 feet away from any morning glory plants.

Each sample for moisture was dried at 110°C to a uniform weight and the moisture percentage computed on the oven-dry basis. After the moisture determinations were completed each sample of soil was broken up, mixed, and moisture-equivalent determinations made on 30-gram (10) subsamples. The samples for nitrates were dried at temperatures below 65°C. Nitrates were determined by the well-known phenol-di-sulfonic acid method on 1:2 extracts from these samples.

EXPERIMENTAL RESULTS

In Table 2 for corn and in Table 3 for sorgo are given the vertical and horizontal distributions of soil moisture percentages and moisture equivalent values in planes perpendicular to the respective crop-fallow boundary lines.

A comparison of the yield figures in Table 2 with those in Table 1 discloses that the border effect was greater for the pair of corn rows involved in this study than for the experiment as a whole. For sorgo, as shown by comparing yield figures in Table 3 and Table 1, the border effect concerned in this pair of rows did not depart far from the average for the experiment as a whole.

The datum for the "reference distance in feet" was the line of centers of the plants in the border row. Positive values represented distances measured into the fallow area perpendicular to the border row. Negative values represented distances from the border row into the cropped area.

Samples were taken into the twelfth or thirteenth foot depths in both the corn and sorgo studies, but below the tenth foot in the corn study the moisture percentage of no sample was less than its moisture equivalent, suggesting that no moisture had been absorbed by the corn plant from below a 10-foot depth. But with the sorgo there was evidence of crop withdrawal of moisture from the twelfth foot, hence the figures for the whole 13-foot depth are given.

For each foot depth the moisture percentage is given above and the average of the duplicate moisture equivalent values is given below. In order to translate percentages of moisture into amount of water per acre the volume weight of the soil in question must be known or assumed. As in a previous study (3), the average of many separate determinations for soils in this area made by Edlefsen and Bodman were assumed to apply to the soils in this study. This average of their values for the volume weight as computed by the writer was 1.2442. An acre foot of soil in this experiment was then assumed to weigh 3,375,900 pounds. These values were the constants used in all subsequent computations where they were applicable.

By a slight modification Lee's (6) definition of "water-deficiency" becomes, "The amount by which the actual water content of a given soil zone (usually the root-zone) is less than the field capacity." At the bottoms of Table 2 (for corn) and of Table 3 (for sorgo) are given the summation of the water-deficiencies (ME—%H_2O) expressed in inches, negative deficiencies being disregarded. This represents the depth of water in effective rainfall or irrigation necessary to bring each foot level of the total depth up to its moisture equivalent (which is assumed to be equal to its field capacity). By a comparison of the water deficiency of one crop with that of the other, as disclosed in Tables 2 and 3, the sorgo has withdrawn a greater amount of moisture than has the corn. In Table 2 for corn the magnitude of the water deficiency decreased progressively until a distance of 10 feet into the fallow was reached, except for the deficiency for the 8-foot distance. This was out of line. For some reason this soil was drier than its position would indicate.

In Table 3 for sorgo the magnitudes of the water deficiencies decreased progressively from the left side to the right. The following gives a tabular comparison of these water deficiencies in inches for sorgo and corn and their differences:

Ref. distance, ft.	-3.5	-1.8	0	2	4	6	8	10	13+
Sorgo	12.27	11.58	10.22	10.89	7.88	5.12	3.06	2.83	2.52
Corn	9.52	10.16	9.57	9.08	4.92	3.84	4.47	2.48	2.58
Difference	2.75	1.42	0.65	1.81	2.96	1.28	-1.41	0.35	-0.06

The water withdrawn by the sorgo crop was greater than that withdrawn by the corn even as far away laterally as the sixth foot.

As in other studies (3, 4), additional significance is attached to the figures for soil moisture and moisture equivalent when the ratio between them is secured. The term "relative wetness" is given to this ratio when multiplied by 100 and it is expressed in per cent. Fig 1 shows the distribution of relative wetness percentages for sorgo (shaded bars) above and corn (solid bars) below for each foot depth. If we assume 100% relative wetness as the field capacity and 50% as the approximate lower limit of plant absorption, the lengths of bars give a graphic representation of the relative amount of available moisture yet remaining at various depths and various distances out into the fallow. It is apparent that there was little difference between the sorgo and corn plants in their absorption in the first 6 feet immediately below the plants. It is true that the soil was a little drier relatively under the sorgo than under the corn. With the eighth, ninth, and tenth feet in depth, however, there was a more noticeable withdrawal relatively with sorgo than with corn. These greater amounts of absorption by the sorgo plants from the fourth and sixth foot horizontal distances from the border row are also reflected in Fig. 1.

A question may arise as to whether the soil moisture conditions may have changed between the date of sampling of the soil in the corn-fallow study on Sept. 16 (Cf. Table 2) and the date for the sorgo-fallow study on October 29. On the latter date a series of samples was taken in the border row of corn and the following values for relative wetness by foot depths were secured: First foot, 48; second, 52; third, 53; fourth, 57; fifth, 63; 6th, 63; seventh, 69; eighth, 81; ninth, 95; and tenth, 107. In only one case, the eighth foot depth, was any foot depth more than 5% relative wetness different on October 29 than on September 16th. At this depth the soil at the latter date was wetter by 11% relative wetness. At this time no significance is attached to this departure. It would seem then that very little change had taken place in the soil moisture conditions between these two dates of sampling.

In Table 4 for corn and in Table 5 for sorgo are given the vertical and horizontal distribution of nitrates expressed as milli-equivalents

TABLE 2.—*Distribution of soil moisture percentages and moisture-equivalent values in a plane perpendicular to a corn-fallow boundary line, field samples taken September 16, 1935.*

Treatment	Inner row		Border row					Fallow	
Yield*	28.5		53.3						
Ref. distance, ft.†	-3.5	-1.8	0	2	4	6	8	10	13
By foot-depths:									
1st $\% H_2O$‡	8.3	8.7	9.8	9.3	12.8	14.3	12.7	15.0	15.4
M_E‖	22.3	23.1	23.2	23.2	22.7	23.0	24.1	23.2	23.7
2nd $\% H_2O$	11.8	10.8	11.7	11.7	14.5	16.7	16.4	17.4	16.4
M_E	22.5	21.2	22.2	22.4	21.5	22.4	22.8	22.7	22.2
3rd $\% H_2O$	11.0	10.2	10.2	10.7	13.3	17.6	14.5	16.1	17.2
M_E	20.4	19.0	18.8	20.1	19.6	20.8	18.8	18.8	19.9
4th $\% H_2O$	9.5	9.7	9.8	9.9	11.3	23.4	15.4	16.1	14.8
M_E	16.2	16.3	16.9	17.6	15.9	24.4	18.1	16.2	15.3
5th $\% H_2O$	9.8	9.0	9.2	10.6	12.0	17.4	12.3	15.9	14.0
M_E	16.5	15.1	15.9	16.2	15.4	20.8	13.6	15.6	13.3
6th $\% H_2O$	8.7	9.6	8.7	10.0	12.6	12.6	11.7	8.6	11.8
M_E	13.0	14.9	13.0	15.8	13.4	14.2	13.8	8.2	11.0
7th $\% H_2O$	13.4	11.3	12.0	13.4	18.2	16.7	16.8	12.8	10.9
M_E	20.6	19.1	18.8	17.7	19.2	18.3	18.8	13.0	10.7
8th $\% H_2O$	11.8	12.2	14.2	18.8	20.6	22.2	26.4	19.4	14.4
M_E	15.8	19.1	20.2	21.1	19.8	22.6	24.8	19.2	14.2
9th $\% H_2O$	11.7	12.7	12.6	11.8	19.9	19.0	——	19.1	——
M_E	12.7	14.5	13.3	13.0	18.2	18.6	——	15.8	——
10th $\% H_2O$	17.1	17.8	17.9	18.5	19.0	19.2	——	17.3	——
M_E	16.4	17.2	16.9	17.4	17.0	17.8	——	15.3	——
Water-deficiency, in.§	9.52	10.16	9.57	9.08	4.92	3.84	4.47	2.48	2.58

*Yield of dried material per 100 feet of row.
†Feet south of south crop row. Negative values were north.
‡Moisture percentage.
‖Moisture equivalent.
§Effective depth of water in inches necessary to bring each foot depth of soil to its M_E. No credit given for $\% H_2O$ above M_E.

of nitrates per kilogram of soil in planes perpendicular to the respective crop-fallow boundary lines. The heavy line in each table delimits the region from which the writer believes there was definite indication of nitrate absorption by the crop in question. The points outside the region of definite withdrawal where a less definite indication of nitrate absorption was manifest are appropriately marked in the respective tables. The values given in Tables 4 and 5 are expressed as milli-equivalent of nitrate per kilogram of soil. These values are numerically equal to pound-equivalents of nitrate per million pounds

TABLE 3.—*Distribution of soil moisture percentages and moisture equivalent values in a plane perpendicular to a sorgo fallow boundary line field samples taken October 29 1935*

Treatment		Inner row		Border row					Fallow	
Yield*		107.0		165.6						
Ref distance ft †		−3.5	−1.8	0	2	4	6	8	10	15
By foot depths										
1st	% H_2O‡	11.4	8.3	11.3	8.8	10.3	12.5	13.8	15.3	15.7
	M_E	23.5	22.1	21.6	22.3	22.2	22.4	22.0	22.3	21.8
2nd	% H_2O	10.2	9.5	11.9	10.5	11.8	13.3	15.2	14.9	15.6
	M_E	20.1	20.4	22.2	21.7	20.9	20.1	20.6	20.1	20.8
3rd	% H_2O	9.2	8.9	9.4	9.2	9.7	10.8	13.1	13.3	14.3
	M_E	18.0	18.2	17.5	17.7	17.2	15.4	15.8	15.8	17.2
4th	% H_2O	8.5	8.8	8.2	7.8	8.2	12.0	13.7	15.4	15.8
	M_E	16.1	16.0	14.4	13.3	13.2	16.2	15.0	16.8	17.2
5th	% H_2O	8.0	7.5	7.0	7.1	7.2	11.8	14.1	14.3	15.7
	M_E	14.0	12.9	11.0	11.7	10.8	14.9	15.0	15.4	16.1
6th	% H_2O	7.6	7.3	7.6	9.0	9.0	12.0	14.2	13.6	15.4
	M_E	12.6	12.1	12.9	15.5	14.0	13.8	15.2	13.5	15.2
7th	% H_2O	8.6	9.3	9.0	9.1	11.4	12.7	15.4	14.1	14.5
	M_E	14.7	16.1	13.8	14.8	15.8	14.3	16.4	15.4	14.4

8th	% H_2O	10.3	9.0	10.0	10.5	12.3	17.2	17.5	20.2	21.4
	M_E	20.1	15.8	19.0	18.8	15.6	19.4	17.6	20.5	20.6
9th	% H_2O	9.6	9.9	9.1	10.4	14.8	18.7	20.4	19.8	26.1
	M_E	14.6	15.2	13.9	16.8	16.2	18.7	19.2	18.8	22.6
10th	% H_2O	13.9	15.0	15.8	13.3	13.3	17.8	19.8	21.6	15.6
	M_E	21.6	20.0	19.8	15.1	14.7	17.2	18.6	19.4	14.6
11th	% H_2O	17.1	21.8	21.2	23.7	23.7	23.0	22.3	22.5	23.7
	M_E	18.9	22.1	21.5	22.0	21.9	19.2	18.2	18.7	19.9
12th	% H_2O	27.8	—	27.7	—	30.7	—	31.4	—	31.6
	M_E	30.3	—	28.9		30.9	—	30.6	—	30.2
13th	% H_2O	20.6	—	23.2	—	21.1	—	21.9	—	24.2
	M_E	18.4	—	21.8	—	20.6	—	20.5	—	22.2
Water-deficiency inches§		12.27	11.58**	10.22	10.89**	7.88	5.12	3.06	2.83	2.52

*Yield of dried material per 100 feet of row

†Feet south of south crop row. Negative values were north.

‡Moisture percentage

‖Moisture equivalent

§Effective depth of water in inches necessary to bring each foot depth of soil to its M_E. No credit given for % H_2O above M_E.

**Appropriate proportional interpolations were made in each of these cases for each foot depth where experimentally determined values were lacking.

TABLE 4.—*Distribution of soil nitrates in a plane perpendicular to a corn-fallow boundary line, field samples taken September 19, 1935, values expressed as milli-equivalents of nitrates per kilogram of air-dry soil.*

Treatment	Inner row		Border row						Fallow
Yield*	28.5		53.3						
Ref. distance, ft.†	−3.5	−1.8	0	2	4	6	8	10	15
Depth by feet:									
1st 0–4 in.	1.00	2.04	1.10	1.32‡	2.05‖	3.27	3.23	3.95	2.67
4–12 in.	0.31	0.48	0.42	0.29	1.19	1.50	1.41	1.51	1.14
2nd	0.11	0.06	0.08	0.08	0.32	0.53	0.57	0.62	0.55
3rd	0.04	0.05	0.05	0.04	0.08	0.27‖	0.50	0.40	0.40
4th	0.04	0.07	0.04	0.06	0.10	0.30	0.38	0.40	0.36
5th	0.03	0.06	0.03	0.05	0.11‖	0.13‖	0.24	0.29	0.31
6th	0.08	0.05	0.03	0.05	0.10‖	0.11	0.17	0.25	0.24
7th	0.17	0.06	0.03	0.04	0.15‖	0.19	0.16	0.29	0.25
8th	0.10	—	0.05	—	0.22	—	0.20	—	0.26
9th	0.08‖	—	0.04‖	—	0.06‖	—	0.12	—	0.17
10th	0.08	—	0.12	—	0.09	—	0.10	—	0.12
11th	0.08	—	0.15	—	0.11	—	0.19	—	0.21
12th	0.14	—	0.20	—	0.20	—	0.27	—	0.24
13th	0.12	—	0.12	—	0.19	—	0.18	—	0.17
Per acre for 10-ft. depth:									
P. eq.§ NO_3	4.29	5.33**	3.75	4.19**	9.15	13.57**	15.06	16.95**	14.55
Pounds NO_3	266	330	233	260	567	841	934	1,051	902

*Yield of dried material per 100 feet of row

†Feet south of south crop row. Negative values were north.

‡The heavy line represents the boundary line of the region from which the writer believes there is definite indication of nitrate absorption by the crop.

‖Instances outside of region above where appreciable nitrate absorption may have taken place.

§Pound equivalent, i.e., equivalent weight in pounds.

**Appropriate proportional interpolations were made in each of these cases for each foot depth where experimentally determined values were lacking.

TABLE 5.—*Distribution of soil nitrates in a plane perpendicular to a sorgo-fallow boundary line, field samples taken October 29, 1935, values expressed milli-equivalents of nitrates per kilogram of air-dry soil*

Treatment	Inner row		Border row						Fallow
Yield*	107.0		165.6						
Ref. distance, ft†	−3.5	−1.8	0	2	4.3	6	8	10	15
Depth by feet:									
1st 0–4 in.	0.70	0.71	0.53	1.33‡	2.41	1.86	2.13	2.17	3.76
4–12 in.	0.15	0.54	0 17	0.82	1.14	1.20	0.99	1.19	2.00
2nd	0.02	0.05	0.02	0.06	0.19	0.44	0.31	0.40	0.76
3rd	0.01	0.02	0.03	0.06	0.05	0.28	0.21	0.28	0.59
4th	0.01	0.02	0.03	0.04	0.08	0.23	0.20	0.24	0.29
5th	0.01	0.02	0.04	0.06	0.10	0.20	0.21	0.21	0.23
6th	0.04	0.02	0.05	0.07	0.16	0.14	0.15	0.21	0.20
7th	0.04	0.06	0.09	0.08	0.15	0.13	0.18	0.21	0.14
8th	0.06	—	0.21	—	0.30	—	0.30	—	0.22
9th	0.06	—	0.02	—	0.13	—	0.26	—	0.19
10th	0.13	—	0.08	—	0.23	—	0.19	—	0.08
11th	0.19‖	—	0.29	—	0.29	—	0.26	—	0.14
12th	0.30	—	0.33	—	0 36	—	0.30	—	0.19
13th	0.14	—	0.40	—	0.20	—	0.31	—	0.15
Per acre for 10-ft. depth:									
P. eq.§ NO_3	2.40	3.88**	3.38	6 45**	9.99	11.98**	11.41	12.66**	17.86
Pounds NO_3	149	241	210	400	619	743	707	785	1,107

*Yield of dried material per 100 feet of row
†Feet south of south row. Negative values were north.
‡The heavy line represents the boundary line of the region from which the writer believes there is definite indication of nitrate absorption by the crop.
‖Instances outside of region above where appreciable nitrate absorption may have taken place.
§Pound equivalent, i.e., equivalent weight in pounds
**Appropriate proportional interpolations were made in each of these cases for each foot depth where experimentally determined values were lacking.

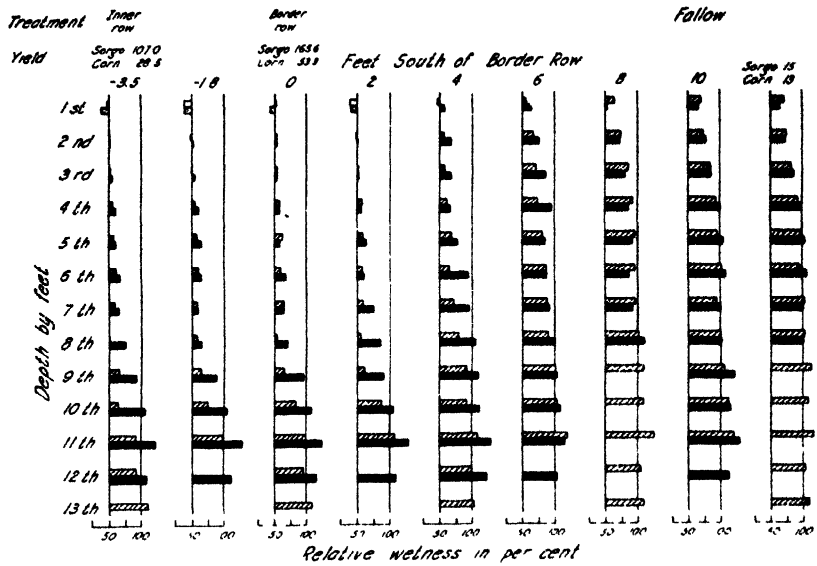

FIG. 1.—A comparison of the residual soil moisture conditions (expressed as relative wetness) between sorgo (bars shaded and above in each pair) and corn (bars solid and below) as secured by samplings from planes perpendicular to the respective crop-fallow boundary lines. The field capacity was approximately 100% and the lower limit of plant absorption approximately 50%.

of soil. As an acre foot of soil under the conditions of these experiments was assumed to weigh 3,375,900 pounds, multiplying each value in the table by 3 3759 gave the number of pound-equivalents of nitrates in the soil at time of sampling. To secure figures in pound-equivalents (P.eq.) given at the bottom of the respective tables, the values for the various foot depths were added together and the resulting sum multiplied by 3.38(3.3759). The corresponding pounds of nitrate were computed by multiplying the pound-equivalents by 62, the equivalent weight of the NO_3 ion. In this case the pound-equivalents of nitrate per acre are numerically more useful as 100 pounds of $NaNO_3$ containing 14% of nitrogen applied to an acre would raise the nitrate content 1 pound-equivalent. With $NaNO_3$ containing 15½% nitrogen, it would require about 90 pounds to make 1 pound-equivalent. The figures given in the tables then represent very roughly the number of 100-pound bags of $NaNO_3$ fertilizer which are equivalent to the amount of nitrate present per acre to a depth of 10 feet. Below is given a tabular comparison of the residual soil nitrates in pound equivalents of nitrates per acre to a depth of 10 feet for both corn and sorgo:

Reference distance, ft.	-3.5	-1.8	0	2	4	6	8	10	13+
Corn	4.29	5.33	3.75	4.19	9.15	13.57	15.06	16.95	14.55
Sorgo	2.40	3.88	3.38	6.45	9.99	11.98	11.41	12.66	17.86

These tabular summaries suggest that sorgo had extracted a greater amount of nitrates from the soil than had corn in this experiment, and that both of these crops had withdrawn nitrates very definitely and positively 2 feet from the border row and definitely, although less so, from 4 feet from the border row. Nitrates are subject to such wide variation that further and more definite statements seem unwise until additional data are secured.

A difference is shown under the conditions of these experiments between corn and sorgo in regard to the residual moisture, and to some extent the nitrates. Certainly the data are too meager to generalize from them in regard to inherent differences always to be expected under similar growing conditions between these crops regardless of variety. The corn was mature several weeks before the sorgo. If a variety of corn which would better take up the full period of the growing season, and presumably thereby give an enhanced yield, had been used, greater consumption of soil moisture and of nitrates would have been expected. On the other hand, if a less vigorous growing variety of sorgo had been selected, it might very well be anticipated that the residual soil differences found in this study would have been reversed.

DISCUSSION

With the extra space available, the yield for a given length of the border row was increased over an equal length of inner row. The former had additional supplies of sunlight, soil moisture, and available soil nutrients. No supplementary tests were conducted to ascertain which of these three was the dominant factor in increasing yields in this case. The relative importance of these three factors may be different with a change of conditions. Thus, Cole and Halsted (2) attributed the increase in yield of the border rows of kafir and milo to the increased supply of soil moisture secured by the plants from the adjoining alleys or fallow at Hays, Kansas.

Hollowell and Heusinkveld (5) attributed the border effect of plats of red clover and alfalfa next to alleys in Ohio as likewise caused by the increased moisture supply. In addition they reported higher yields of border rows north of the alleys than south of them. It seems obvious that this may have been due to the greater amount of sunlight received by the row north of the blank space (the alley) over that received by the row south of it. Where, as in humid regions and under adequate irrigation, soil moisture is not a limiting factor, obviously a very important cause of the increased growth of the border row must be the additional source of plant nutrients at the disposal of the border plants.

If in any given case, one of these factors would be the dominant cause it would naturally follow that greater amounts of the other two would be utilized. Thus, if soil moisture were the determining factor, the additional supply would cause a chain of events which would almost certainly result in the utilization of a greater amount of sunlight and a greater amount of plant nutrients. The same would apply if any of the other factors were the determining one. The results secured in a way then might have been anticipated from a

qualitative standpoint. In fact Conrad and Veihmeyer (4) have shown use of soil moisture by border rows of grain sorghum laterally into the fallow. Their data were collected to a depth of only 6 feet. The study reported herein was made under somewhat similar growing conditions, but yields and residual soil moisture and nitrate determinations into the twelth and thirteenth foot depths are here included as well as similar data secured with corn

SUMMARY

Where growing conditions were very similar to those under dry-farming, plants in rows bordering on uncropped areas yielded more than did plants in inner rows. Soil samples taken in planes perpendicular to the crop-fallow boundary lines showed a definite use of soil moisture 6 feet away laterally with sorgo and 4 feet away with corn, and a definite use of nitrates 4 feet away laterally with both crops.

Under the main body of the crop corn plants gave evidence of definite absorption of moisture from the ninth foot depth and of nitrates from the eighth foot, while sorgo gave evidence of absorption of moisture from the twelfth foot and of nitrates from the tenth foot.

The differences between these crops as disclosed in this study may not be of fundamental nature but may be only differences in degree. It is possible that the conditions as found for sorgo and corn might have been reversed had a much less vigorously growing variety of sorgo and a much more vigorously growing variety of corn been used.

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THE MASS-PEDIGREE METHOD IN THE HYBRIDIZATION IMPROVEMENT OF CEREALS[1]

J. B. HARRINGTON[2]

DURING the past 12 years several methods of handling hybrid populations have been used under the dry open plains conditions at Saskatoon in western Canada. The straight pedigree method, while desirable in several respects, proved expensive and distinctly limited the amount of material carried. The straight mass method allowed the carrying of a large volume of material, but was very slow. Modification of the mass method, by selecting whenever feasible during the years of segregation and running individual plant progeny tests where desirable, is believed to be a suitable combination plan. It is this combination which is referred to as the mass-pedigree method.

In order to state clearly the case for the combination method, it is necessary first to consider the generally accepted use of the two methods which it combines. The pedigree method has been used very extensively in the hybridization improvement of self-fertilized crops in Canada, the United States, Great Britain, and Australia, as well as in other countries. It has been described by Love (9),[3] Hayes and Garber (5), and others. Essentially it consists of selecting promising plants in several segregating generations commencing with F_2, and each year after F_2 growing an individual progeny of each selected plant. A progeny is bulked and considered to be a pure breeding line as soon as all of the plants appear to be uniform for easily observable morphological characters A uniform appearing progeny may sometimes be bulked as early as F_3, as mentioned by Love (9), or F_4, as stated by Biffin and Engledow (1). Hayes and Garber (5) prefer on the whole not to consider any progenies as lines before F_5. On account of the large amount of selecting and progeny testing associated with the pedigree method, many breeders have recently commenced using the mass method as an economical substitute.

The mass method is now used considerably in various countries. It has been employed in Germany and Sweden for many years. Until comparatively recently it was not used much in Canada and the United States, although it was described by Newman (10) in 1912. During the past 10 years an increasing number of breeders in these countries have commenced to use the method in one form or another. In the United States the mass method has been described by Love (9), Hayes and Garber (5), and others. Its usefulness has been pointed out by Florell (3) and, in a specialized form, by Harlan and Martini (4). Recently, Hiorth (6) detailed the manner in which Baur uses the mass method and Bohorodski (2) recommended it as being far superior to the pedigree method.

[1]Contribution from the Department of Field Husbandry, University of Saskatchewan, Saskatoon, Sask., Canada. Also presented at the annual meeting of the Society held in Washington, D. C., on November 18, 1936. Received for publication February 19, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 384.

Briefly, the mass method consists of growing the segregating generations of a cross year after year without selection until a large proportion of the individuals constituting the population are reasonably homozygous. At that stage selections are made, progenies grown and the desirable uniform progenies bulked separately as pure breeding lines. Love (9) recommended taking selections as early as F_6. On the other hand, Baur, according to Hiorth (6), does not select for progeny testing until F_{10} to F_{12}.

Regardless of the method of handling the segregating generations, the bulking of the plants of a progeny to form a line is not done until the progeny appears to be homozygous. In narrow crosses or in crosses where the parents differ by very few obvious characters lines are taken earlier than in interspecific crosses and those involving many gene differences. Considering, for example, an ordinary cross in which the parents differ by 8 to 10 allelomorphic pairs of importance, it may be expected that reasonably uniform lines are obtained in F_5 or F_6 where the pedigree method is used and in F_9 or F_{10} with the straight mass method.

USE OF THE PEDIGREE AND MASS METHODS AT SASKATOON

We have used the pedigree method at Saskatoon for various crosses during the past 12 years. In addition to its being expensive this method has been found to be much less effective in some years than in others. For example, critical selection for straw strength, resistance to some diseases, and, to a large extent, plant height, earliness, and resistance to shattering, is not possible in dry seasons, yet the latter occur frequently. Selection in F_2, under such conditions, requires carrying on several times as many plants as would be necessary under favorable selection conditions. The efficacy of selection in generations after F_2 is also reduced in dry years but not to the same extent, owing to there being progeny tests and owing to the proportion of homozygotes being much larger.

The use of the mass method was commenced at Saskatoon in 1924. The uncertainty of the length of time this method might take was brought forcibly to our attention in the first cross carried by this method. The cross was continued in mass until 1929 when selection was made for easily observable morphological characters and progenies were grown in 1930. The period 1929 to 1934 was dry and afforded no satisfactory opportunity to select for straw strength. It was not until 1935 that the lines could be studied effectively for that character. Looking back on the earlier years of this cross, it was apparent that very effective selection for straw strength and a number of other characters could have been accomplished in the moist years of 1927 and 1928 with a resulting saving in space and time if the mass method had been modified.

MODIFICATION OF THE MASS METHOD

Modification of the mass method is not a new thing. Selection during the segregating generations was practiced at Svalof previous to 1912, according to Newman (10). It is now practiced by many breed-

ers and has been mentioned recently by Florell (3), Lamb (8), Kocnar (7), and others. This "Modified Mass Method," as it may be called, is considered generally to be an improvement over the straight mass method.

Modifications of the mass method were commenced by the writer in 1931. The modifications consisted in selecting for desirability in one or more important characters when circumstances were favorable. A wet season or a combination of long straw and high winds sometimes presented an excellent opportunity for selection for resistance to lodging as well as for several other characters. Such opportunities were taken advantage of, whether they occurred when a cross was in F_2 or in any later segregating generation. Again, if a satisfactory disease epidemic occurred naturally, or was induced artificially, selection for resistance was made in the mass plats, irrespective of the generation they were in. In very dry or hot seasons, selection for drought and heat resistance was carried on.

THE MASS-PEDIGREE METHOD

These modifications led to the introduction of the progeny test as a further feature of the method and owing to this feature the process was called the "Mass-Pedigree Method." The plan is to go on with individual plant progeny tests whenever the circumstances have particularly favored selection in the preceding year. The method may be illustrated as follows: A given cross, with or without mass selection in F_2, is carried on in mass to F_3. In F_3, owing to a favorable season, very efficient selection reduces the population to a twentieth of its size. The selected plants, instead of being bulked, are separately threshed and sown in progeny rows in F_4. In F_4 selection is carried on as in the pedigree method. The effectiveness of the selection is influenced by the seasonal conditions as in the pedigree method. Where the conditions do not favor efficacy in individual plant selection the selection work may be reduced to a minimum by bulking all the promising progenies instead of selecting single plants from them and bulking those. The F_5 is grown in mass with mass selection if desirable and in F_6 selection of plants for F_7 progeny tests is made. The selection in F_6 may or may not be very effective, depending on the conditions, but in any event it does not need to be postponed even in an unfavorable year, as the selection through the years has already eliminated most of the undesirable types and one has a population which is different in character from the wholly unselected plat of the straight mass method.

In the foregoing illustration of the operation of the mass-pedigree-method, it was considered that individual plant progeny tests were made in F_4, following individual plant selection in F_3. However, if, owing to propitous circumstances, critical selection is practiced in F_2, the progeny tests would be made in F_3; and if the effective selection is in F_4 or F_5, the progeny tests would be made in F_5 or F_6, respectively. In the latter cases many progenies should be sufficiently homozygous to use as lines in F_6 or F_7. In narrow crosses, where the parents are considered to differ by very few important genes, lines are taken out as early as F_5.

The mass-pedigree method is designed to utilize the main feature of the pedigree method—the individual plant progeny test—just when it is likely to be most worthwhile. It thereby saves the expense of much of the progeny testing connected with the pedigree method. On the other hand, the combination method would be expected to take a year longer and not have the selection advantage of continuous pedigree records and progeny performances each year.

It should be noted that the mass-pedigree method is cheaper when the individual progeny tests are made in F_4 or F_5 rather than in F_3. In F_2 the population is almost entirely heterozygous, several of the desired genes are more or less dominant, several are recessive, and usually the manifestations of some of the most important genes, those concerned with quality and yield difference, are not visible. This being the situation, if conditions favor selection in F_2 a generous number of selections must be taken in order that the desired genotype or heterozygotes capable of producing it later may be retained. This may mean a very large number of progeny rows in F_3. If, however, selection for progeny tests is made in F_3, the situation is different. An appreciable portion of the population is homozygous and the chances of having the desired genotype in the population are much greater than in F_2. Therefore, more rigid selection can be practiced and relatively fewer progenies grown in F_4. If the selection for individual progeny tests is not made until F_4, the situation is again different. The percentage of homozygoty has risen considerably and with it the Mendelian chances of getting the desired type have increased greatly. Consequently, the work of selecting and progeny testing is less than where the critical selecting occurs in F_3.

USE OF MASS-PEDIGREE METHOD AT SASKATOON

The mass-pedigree method has been used in wheat, oat, and barley crosses at Saskatoon, and the new wheat crosses which in 1936 were in F_1 and F_2 are to be handled by this method. In the case of several of the oat and barley crosses it was found desirable to use a further modification which consisted of carrying on the selected progenies (mostly in F_3) not as one large mass but as separate small masses, one for each progeny. This was done when the progeny year was extremely dry (1933) and it was desirable to observe the more drouth-resistant progenies for another year under different conditions which would not have been possible if they were massed. On the other hand, it was not considered worthwhile to go to the additional expense of having immediately another year of individual plant progeny tests on this material.

/ The mass-pedigree method is expected to be very useful in our cereal breeding and we have concluded that various crosses which we have carried throughout by the pedigree method might better have been conducted by the combination method. For example, some crosses were made in 1925 and the F_2 grown in 1926. The season of 1926 was not particularly suitable for selection but both 1927 and 1928 were very favorable. It is doubtful whether the large number of F_3 progeny tests, made according to the pedigree method in 1927, were necessary.

The mass-pedigree method involves distinctly less progeny testing than the pedigree method and therefore allows more crosses to be carried. It will approach the pedigree method most closely in cost when progenies are run in F_3 following F_2 selection, as at that stage more progenies are required than at any later stage. It will be increasingly cheaper accordingly as the progeny test is made in later generations, as in F_4 or F_5. In the latter case, the method appears to be several times cheaper than the pedigree method.

The discussion of the use of the mass-pedigree method has been limited for the sake of simplicity to simple crosses However, it can be applied equally well to a number of single crosses or to back crosses, double crosses, three-way crosses, or mixed crosses.

COMPARISON OF THE MASS-PEDIGREE METHOD AND OTHERS

The mass-pedigree method has the following advantages over the pedigree method. (a) It is elastic and efficient in the use of progeny tests of individual plants because such tests are only made when conditions the previous year have been particularly favorable for selection; (b) it allows the handling of one and a half to three times as much material owing to having usually only one individual plant progeny test in the segregating generations, and to bulking the selections from that progeny test. The mass-pedigree method has two disadvantages compared with the pedigree method, *viz.*, (a) it usually will take a year longer; and (b) it allows less critical selection in at least two of the segregating generations on account of there being no pedigree records or "sib" performances to serve as guides.

Compared with the straight mass method, the mass-pedigree method has distinct advantages, viz., (a) it saves about 2 years' time; and (b) by allowing critical information to be obtained when opportunity favors it may save more than 2 years' time, especially where resistance to biologic pests and weather resistance is sought. On the other hand, the mass-pedigree method is (a) more expensive on account of having usually one individual plant progeny test in F_2, F_3, or F_4 and the repetition of selecting in several generations, and, (b) it gives less time for natural selection to assist the breeder.

The mass-pedigree method has the advantages of the "modified mass method," wherein mass selection is practiced as desirable throughout the segregating generations, and the further advantage of utilizing the most important feature of the pedigree method, the "progeny test," at the time when it will be most effective. The new method should, on the average, save a year's time compared with the modified-mass method. On the other hand, it is somewhat more expensive than the latter.

The precise usefulness of any particular method of handling hybrid populations depends greatly upon the circumstances surrounding the breeder. It is quite possible that two breeders differently situated will use different methods and each with very good reasons. It is often the case that one breeder will use several methods at the same time. For example, some present-day breeders use both the modified-mass and pedigree methods on an important cross. The mass-pedigree method

is presented here as a further alternative which, under some circum. stances, proves especially useful.

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THE NECESSITY OF MINOR ELEMENTS FOR THE GROWTH OF TOMATOES IN A POOR SOIL[1]

J. S. McHargue and R. K. Calfee[2]

INVESTIGATORS have revealed in recent years that some areas of soil in different parts of this country show a response in the growth of plants when treated with compounds of one or more of the minor elements. It is the purpose of the experiments described in this paper to ascertain if a certain type of soil known to be deficient in calcium, phosphorus, nitrogen, and potassium was also deficient in the minor elements copper, manganese, zinc, boron, bromine, chlorine, fluorine, and iodine.

The type of soil selected for the experiment is a sandy silt loam which is more or less typical of much of the hill and ridge area in the Eastern Coal Measures of Kentucky.

The land was cleared of a dense forest about 75 years ago and was cultivated to corn, wheat, and oats for about 25 years. It was then abandoned to natural processes for nearly 30 years during which time a second growth of oak, hickory, poplar, pine, sumac, and broom sedge grew on the soil. The soil was cleared a second time about 15 years ago and has been kept since then in pasture consisting of orchard grass, redtop and, more recently, lespedeza. It is estimated that this soil will produce about 15 bushels of corn per acre during a favorable season. No commercial fertilizer of any kind has ever been added to the soil, and for this reason it is well suited for experiments to ascertain if the minor elements have been depleted to the same extent as the major elements. The soil may be regarded as being typical of a large area of abandoned farm land in the eastern half of the United States.

Agronomists state that a chemical analysis of a depleted soil will not reveal all the information they may wish to have for recommending a fertilizer treatment for the most important farm crops. If a soil is analyzed for the major elements, nitrogen, phosphorus, and potassium, as is usually the case, the agronomist may not have all of the important facts before him for a diagnosis. A complete chemical analysis including the minor elements may reveal more important information than is possible to obtain when only determinations of nitrogen, phosphorus, and potassium in a soil are made.

A rather complete silicate analysis for both the major and minor elements was made of the depleted sandy silt loam soil and, for comparison, of a representative bluegrass clay loam soil whose productiveness is estimated at 75 bushels of corn per acre during a fa-

[1]Contribution from the Department of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky. The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. The paper was also read before the Division of Fertilizer Chemistry of the American Chemical Society at the meeting of the Society held in Pittsburgh, Pa., September 7 to 11, 1936. Received for publication February 22, 1937.

[2]Head of Department and Assistant, respectively.

vorable season. The results of the chemical analyses are shown in Table 1.

TABLE 1.—*Analyses of a badly depleted soil from Laurel County and a fertile soil from Fayette County, Kentucky.*

Elements	Percentage of moisture-free soil	
	Coal measures soil, Laurel County	Maury silt loam soil, Fayette County
Ignition	3.880	6.49
Silica (SiO_2)	86.430	72.90
Alumina (Al_2O_3)	6.160	9.48
Ferric oxide (Fe_2O_3)	1.450	4.24
Manganese oxide (MnO)	0.014	0.53
Titanium oxide (TiO_2)	0.800	1.23
Calcium oxide (CaO)	0.152	0.75
Magnesium oxide (MgO)	0.162	1.46
Phosphorus pentoxide (P_2O_5)	0.018	0.77
Sodium oxide (Na_2O)	0.309	0.33
Potassium oxide (K_2O)	0.675	1.38
	100.050	99.56
Nitrogen (N)	0.093	0.215
Copper (Cu)	0.0007	0.002
Zinc (Zn)	0.0028	0.012
Moisture in the air dry soil (H_2O)	1.00	2.66

The experiment consisted of 42 soil cultures of 6.5 kg each contained in acid-resistant earthenware jars. The acidity of the soil in all jars was brought from pH 5.8 to pH 6.6 with pure calcium carbonate. Tomato seedlings, germinated in purified sand and selected for uniformity of size and color, were then transplanted, one to each jar Group A consisted of 18 soil cultures which received no further treatments. Group B consisted of 12 cultures each of which received a total of 5 grams of $Ca(NO_3)_2.4H_2O$, 2.5 grams KNO_3, 2.0 grams KH_2PO_4, 1.5 grams $MgSO_4$, $7H_2O$, and 0.05 gram $FeCl_3$, as basal mineral nutrients added in solution throughout the period of growth. Group C consisted of the remaining 12 cultures which received the same quantities of the major elements and sufficient of the minor elements to give 5 p.p.m. Mn, 2.5 p.p.m. Zn, 2 p.p.m. Cu, 0.65 p.p.m. B, and 2.5 p.p.m. each of I, F, and Br, to each culture. All cultures were kept at a water content of 60% saturation. The mineral nutrients were added weekly in sufficient distilled water to bring the weight of the culture to a predetermined total. As growth progressed, allowance was made for the weight of the plants when water was added.

For the first 10 days growth was slow and uniform in all cultures after which the plants treated with the minor elements grew faster than those in the other groups. Fig. 1 illustrates the extent of growth made in 21 days, the photographs being comparable in regard to size. The plants of group B were slightly larger, especially the stems, but were distinctly lighter in color than those of group A. The plants of

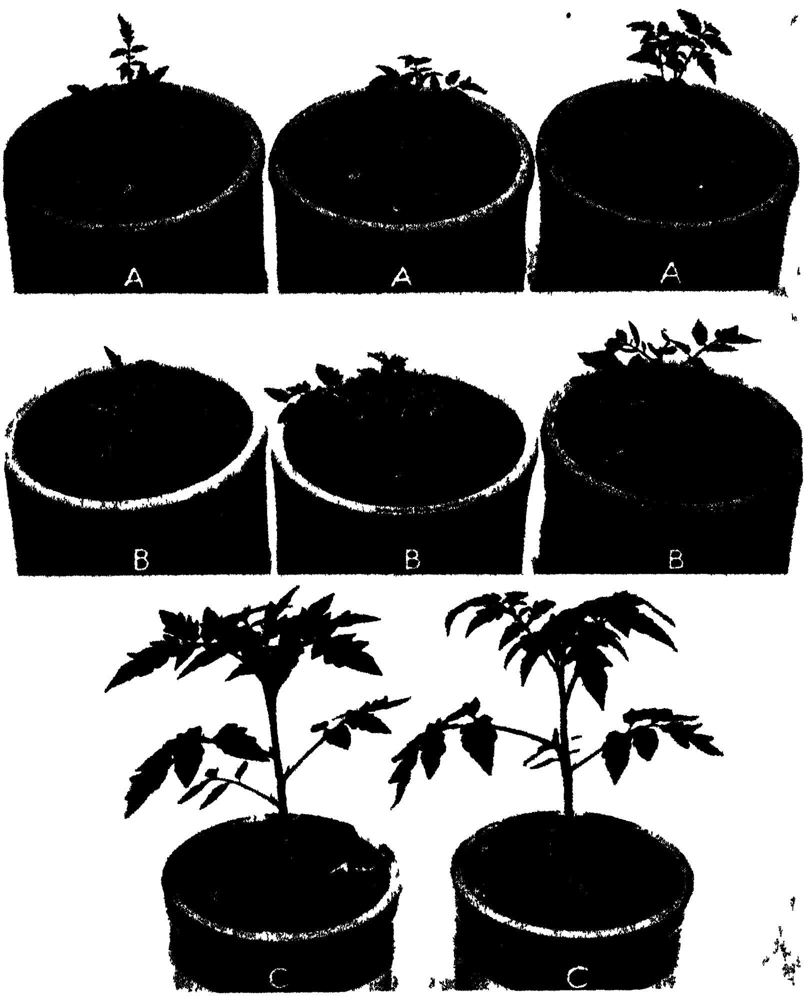

FIG. 1.—The effect of treating a badly depleted soil with pure compounds of the major and minor elements on the growth of tomato plants. Group A, untreated soil; group B, major nutrients added; group C, major and minor nutrients added.

group C were normal in every respect, comparing favorable with plants grown on a fertile bluegrass soil. After a period of 6 weeks, the untreated plants had made practically no more growth than in the first 10 days. The plants of group C had made a luxuriant vegetative growth and had produced blossoms, while the group treated only with the major elements had made about three-fourths as much growth and were apparently experiencing some disorder of the growing point. The abnormal young growth was not typical of boron deficiency; however, the extent that complications by other deficiencies

may modify the characteristic symptoms of insufficient boron is not known. The height of the plants at this time averaged 6 inches for group A, 18 inches for group B, and 25 inches for group C. These differences in growth were maintained rather proportionately to the end of the experiment. Fig. 2 shows the condition of the plants at approximately 16 weeks after transplanting.

FIG. 2.—The effect of treatments with the major and minor plant nutrients on the growth and maturation of tomato plants. The plant on the left received adequate amounts of compounds of both the major and the minor elements. The center plant received pure compounds of only the major elements, N, P, Ca, Mg, and K applied at the same rate. No treatment was given the plant at the right other than the correction of soil acidity to a pH of 6.6 by the addition of pure calcium carbonate.

Pollination was effected by brushing the pistils of the blossoms twice daily with a brush well dusted with pollen. Few blossoms were produced on the untreated plants, and these failed to set fruit up to the time of maturation of the treated groups and the conclusion of the experiment. Approximately 25% of the blossoms produced on plants treated with applications of the major elements set fruit, while a set of 40% was obtained in the group that received both the major and minor elements. The fruits of this group matured about 2 weeks earlier than the fruits of group B. The fruits were gathered as they ripened and the weights recorded. The total yield of the ripe fruit was 1.2 kg for group B and 3.033 kg for group C, a very substantial increase for the plants treated with the minor elements. This increase was due to both size and number of the individual fruits.

The analyses of the plants, conducted in accordance with the recommendations of the Association of Official Agricultural Chemists, are given in Table 2.

TABLE 2.—*Analyses of tomato plants and fruits in percentage of dry weight when grown in pot cultures in the greenhouse and in the field.*

Elements	In greenhouse					In bluegrass soil in the field	
	Vines			Fruit		Vines	Fruit
	Group A	Group B	Group C	Group B	Group C		
Ash, crude	10.71	14.46	11.47	7.8	10.38	20.00	11.70
Silica (SiO_2)	0.223	0.412	0.389	0.845	0.621	0.435	0.523
Copper (Cu)	0.0021	0.0008	0.0008	0.0001	0.0006	0.0017	0.0010
Iron (Fe)	0.040	0.036	0.034	0.015	0.015	0.016	0.0048
Manganese (Mn)	0.0215	0.0225	0.0318	0.0037	0.0052	0.0262	0.0043
Zinc (Zn)	0.0040	0.0032	0.0031	0.0031	0.0033	0.0019	0.0012
Calcium (Ca)	5.280	3.280	2.730	0.131	0.080	2.650	0.333
Magnesium (Mg)	0.626	0.312	0.571	0.100	0.107	0.610	0.128
Phosphorus (P)	0.065	0.074	0.055	0.163	0.096	0.451	0.317
Sodium (Na)	0.505	0.400	0.296	0.116	0.052	0.445	0.874
Potassium (K)	1.288	2.248	1.395	3.110	2.664	4.350	4.420
Fluorine (F)	0.0018	0.0006	0.0003	0.0002	0.0010	0.0019	0.0014
Nitrogen (N)	2.422	1.194	0.785	2.120	2.120	4.490	3.010
Protein (N x 6.25)	15.138	7.463	4.906	13.250	13.250	28.063	18.813
Moisture (H_2O)	9.62*	9.50*	8.91*	95.15†	96.20†	6.57*	96.60†
Total dry weight, av. grams per pot	2.00	6.35	18.14	4.75	15.30	——	——

*Air-dry vines.
†Ripe fruit.

The experimental plants contained considerably less ash than the plants grown on a fertile bluegrass soil in the field. The ash content was exceedingly low in the vines of all groups, although in the fruits from the plants treated with the minor elements the total ash was approximately the same as in the fruits produced under the most favorable conditions in a fertile soil.

Manganese, zinc, iron, and magnesium were present in the plants which were grown in the pots in quantities found in the tomatoes produced under field conditions with the possible exception of the vines in group B. Sufficient data are as yet not available to state definitely whether or not the slightly chlorotic condition of the plants of this group is wholly responsible for the low magnesium content obtained. In the experimental cultures zinc and iron were present in both vines and fruits in slightly greater amounts than in the plants grown under field conditions. Manganese was slightly lower, except in the vines of plants treated with manganese sulfate. These elements were probably not factors in the growth differences obtained between the various groups.

Sodium was lower in the plants grown in the pot cultures than in those grown in the field and silica was slightly less. These two elements are of questionable nutritional importance and have not been thoroughly investigated. It is interesting to note that silica, in all cases, was higher in the fruits than in the vines.

Calcium was present in the soil in sufficient quantity for all growth requirements. The vines produced in the pot cultures contained considerably more calcium than those grown in the field, while the calcium in the fruits was the reverse. The heavy addition of calcium carbonate in adjusting the pH of the soil probably accounts for the high calcium content of the untreated vines.

As indicated by analysis of the plants, copper and fluorine, together with nitrogen, phosphorus, potassium, and possibly calcium, are the limiting elements in this soil. Insufficiency of material prevented the determination of iodine, bromine, and boron. The physical appearance of the group B plants at times, suggested an insufficiency of boron for normal growth.

There is no correlation between the content of the major and minor elements in the tissues of the plants that suggests dependency of one upon the other. In consideration of the marked difference in growth and appearance of the three groups of plants, it can be safely assumed that the function of the minor elements with which we have experimented is primarily concerned in the synthesis of the organic constituents in the metabolism of the plants.

The untreated soil will produce as much as 15 bushels of corn per acre under field conditions during a favorable season, which is a relatively much greater yield than that obtained with the tomato plants in the untreated soil. However, the root growth of corn plants in the latter part of the growing season, is much more extensive than that of tomato plants and therefore an opportunity to absorb more of the necessary elements is afforded because of the contact with a greater number of soil particles. In previous experiments with tomatoes grown in a fertile soil under field conditions a response was ob-

served by treating the soil with small amounts of compounds of the minor elements. This observation indicates that the tomato plant has a specific requirement for certain of the minor elements or derives a benefit from a combination of certain of the minor element compounds.

The results of this experiment confirm the findings of other investigators in recent years in this country in that an increasing number of soils are being reported which show a response in the growth of crops where minor element compounds have been added in carefully controlled experiments.

SUMMARY

The results of this experiment show that very marked beneficial effects were obtained from the addition of small quantities of compounds of the minor elements to cultures of soil in contrast with the results obtained when adequate amounts of compounds of the major elements only were added to other cultures of the same soil.

From the size and general appearance of the fruit produced from the soil cultures that received compounds of the major elements alone, it was apparent that this fruit was of inferior quality in comparison with the fruit produced from the soil cultures that received compounds of both the major and minor elements.

BOUND WATER AND ELECTRICAL CONDUCTIVITY AS MEASURES OF COLD RESISTANCE IN WINTER WHEAT[1]

C. A. VAN DOREN[2]

COLD resistance as used in this paper refers to endurance of plants to periods of low, sub-freezing temperatures which frequently occur in winter wheat growing areas.

The investigation has included the following studies: (a) The amount of total, free, and bound water in a limited number of winter wheat varieties by use of the calorimetric, heat of fusion of ice method as described by Robinson (9)[3]; (b) the influence of certain environmental conditions on the state of water in winter wheat plants; (c) electrical conductivity of distilled water extracts of frozen, and subsequently thawed, tissue as a measure of the extent of injury sustained by winter wheat from exposure to low temperatures; and (d) electrical conductivity of distilled water extracts and state of water in crown tissues compared to leaf tissues.

MATERIALS AND METHODS

Field grown winter wheat tissues used in this investigation were collected during the late winter and early spring of 1932 and 1933. Temperatures which occurred previous to collections and the probable hardiness of the field grown material at the time of collection are given where the experimental data for the respective tests are presented. The greenhouse material was hardened in an artificial refrigerator.

Bound water, as the term is used in this paper, is the difference between the total water and the free water content determined as described below. The total water content was determined by drying the samples to constant weight in an oven at 100° C in 1932 and in a vacuum oven at 85° C in 1933. The free water was determined by the calorimetric method described by Robinson (9) with only slight modification. Approximately one-third gram of tissue was weighed in a tinfoil cup of known weight and the edges of the cup tightly pressed over the top of the sample. Samples were dropped in glass vials and placed for 5 to 12 hours in an electric freezing chamber regulated at —20° ± 0.1 C (Fig. 1). A silvered Dewar flask was used for a calorimeter into which 10 ml of water slightly above room temperature were measured. When the water and calorimeter had attained equilibrium, the initial temperature was read. The sample was then quickly transferred to the calorimeter. When the sample of frozen tissue had thawed and its temperature had come to equilibrium with the water in the calorimeter, the final temperature was read. These temperatures were determined by a 38-gauge iron-constantan thermopile attached to a Leeds and Northrup potentiometer.

Robinson's (9) formula was used to calculate the amount of free water. Thermal capacity of the calorimeter was determined by measuring the heat lost when

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[3]Numbers in parenthesis refer to "Literature Cited", p. 401.

frozen distilled water samples of known weight were thawed in the calorimeter. Specific heat of the green material was calculated by Robinson's (9) formula from the specific heat of each of the two fractions, water and dry matter. The specific heat value of dry corn leaf tissue as determined by Holbert and Burlison (6) was used in this investigation as the assumed specific heat of dry wheat tissue.

FIG. 1.· Equipment used for measuring free and bound water by calorimetric method. 1, ice box; 2, table supporting switchboard and potentiometer; 3, analytical balance; 4, cold or reference junction; 5, water bath for Dewar flask; motor, with stirring rod, attached to upright support; note thermopile extending between 4 and 5; an extra Dewar flask of the type used in water bath on a clamp extending out toward 4; 6, electric freezing chamber regulated by toluol-mercury thermostat at —20° + 0.1 C.

Briggs (2) defines bound water as that portion of the water in a system containing colloid and crystalloid which is associated with the colloid together with those ions which form a part of the colloid complex. He stated that the calorimeter method fails to differentiate between water associated with the colloid and the crystalloid fractions of the non-water components of the sample, as at any temperature down to the eutectic point a certain portion of the water will remain in solution. The proportion of water which remains liquid in crystalloids in plant tissue at —20° C has not been determined, and in the present investigation it is considered bound together with that associated with colloids. In fact, all the water in biological tissues may be bound in some way or other and changing conditions affect only the force with which it is bound.

Inclusion of air with the tissue within the tinfoil cups probably introduces the most serious error in the method which was used. The enclosed air may raise the calculated bound water value by tending to insulate the frozen tissue and hence preventing rapid and complete thawing. The error should, however, be fairly uniform thruout the experiments here reported. As pointed out by Robinson (9), inclusion of the tissue within tinfoil cups is essential in order to prevent such

serious errors as (a) evaporation of water from the specimen, (b) heat of solution of any soluble substances while in the calorimeter, and (c) floating of specimen on surface of water in calorimeter.

Electrical conductivity tests were made on water extracts of frozen and subsequently thawed tissue in a Washburn (11) type B conductivity cell attached to a wheatstone bridge. The current was supplied by dry cells thru a high frequency oscillator. Duplicate 2-gram samples were placed in 1 × 8 inch pyrex tubes, frozen for 10 hours at —20° C, 25 ml of distilled water were added, and electrical conductivity of the extract determined after allowing 8 hours for diffusion of electrolytes. These tests were made in a room the temperature of which was not thermostatically controlled, but care was taken to avoid extreme fluctuations. In future work with varieties of wheat which differ less in cold resistance than Minhardi and Blackhull, the varieties used in this study, it would be advisable to make the conductivity tests at a thermostatically controlled temperature.

The significance of a difference between any two means, unless otherwise stated, was tested by Fisher's "t" method (4) as applied to a small number of unpaired observations. A P value of .05, giving odds of 19:1 against the deviation being due to chance, has been accepted as significant.

The individual figures of percentage of water in green tissue were calculated to tenths, but to avoid undue errors in calculation of differences between means the averages were carried to hundredths.

DISCUSSION OF RESULTS

Total, free, and bound water were determined on leaves of Minhardi, Turkey Red, Blackhull, Illinois No. 2, and Tenmarq winter wheat varieties collected in the field on March 17 and March 31, 1932. Leaves of the Arlando variety were also included on the later date. Temperature conditions were more favorable for hardening preceding March 17 than March 31 (Table 1). The leaves of Minhardi, Illinois No. 2, and Tenmarq contained a significantly higher percentage of total water on March 31 in the unhardened condition than on March 17 (Table 1). Blackhull contained a significantly lower amount on the late date. The percentage of total water in leaves of Turkey Red was not significantly changed by occurrence of conditions unfavorable for hardening.

Newton (8) stated that the moisture content of hardened tissues tends to be inversely proportional to hardiness, and that it fluctuates less with changes in weather conditions with hardy than with nonhardy varieties.

The varieties are arranged in Table 1 according to decreasing resistance to low temperatures with the probable exception of Illinois No. 2, the cold resistance of which has not been accurately established. Low total water, low free water, and high bound water of leaves on March 17, although in a hardened condition, were not consistently related to the known resistance of the winter wheat varieties to low temperatures: Minhardi, the most hardy variety, contained less total water than any of the other varieties except Illinois No. 2. Minhardi contained significantly less free water per gram of dry weight than Turkey Red and Blackhull, and also less than Tenmarq, but the difference was not significant. There were no significant differences between varieties in bound water content on March 17.

TABLE 1.—*Total, free, and bound water in leaves from several varieties of field-grown winter wheat sampled March 17 and March 31, 1932.**

Variety and date collected	Total water in green tissue, %	Mg water per gram dry tissue		
		Total	Free	Bound
Minhardi				
March 17	71.30	2,484	2,083	401
March 31	72.58	2,649	2,190	458
Turkey Red				
March 17	74.00	2,844	2,432	412
March 31	74.95	3,019	2,390	629
Blackhull				
March 17	75.08	3,014	2,471	543
March 31	73 28	2,744	2,743	401
Illinois No. 2				
March 17	71.25	2,482	1,977	505
March 31	73.68	2,809	2,258	552
Tenmarq				
March 17	73.02	2,710	2,119	591
March 31	75.42	3,073	2,600	473
Arlando				
March 17	——	——	——	——
March 31	78 30	3,609	2,967	643
Mean difference required to give odds 19:1	1 24	134	196	224

*Air temperatures were about 33° F when the leaves were collected Low minimum temperatures varying from 5° to 33° F occurred daily during a 12-day period previous to March 17. Minimum temperatures recorded during an equal number of days previous to March 31 varied from 24° to 42° F The above figures are average values of five samples for each variety on each date. The significance of differences between the above means was tested by the analysis of variance method.

The total, free, and bound water was determined on leaves from 6-weeks-old Minhardi and Blackhull winter wheat plants grown in the greenhouse in soils of high and of low levels of fertility (Table 2). The plants were hardened for 3 weeks in a low temperature cabinet at alternating temperatures of 2° C at night and greenhouse temperature (16° C) during the day. Harvey (5) found alternating temperatures satisfactory for hardening of plants, altho Tumanov (10) and Dexter (3) have found a continuous low temperature more satisfactory. The total amount of water in both varieties was greater in the plants grown in the soil of high than of low fertility. The amount of free water per gram of dry weight was significantly greater in Minhardi in the soil of high fertility. No significant differences in bound water content were found in the plants grown on the different soils. The total water content and the state of water in the two varieties when grown on the same soil may also be compared. The total water content per gram of dry tissue was greater in Blackhull than in Minhardi. Blackhull leaves contained more free water per gram of dry tissue than Minhardi leaves when grown on the soil of low fertility but not when grown on the soil of high fertility. Differences between the two varieties in bound water content were not significant.

TABLE 2.—*Total, free, and bound water in leaves from Minhardi and Blackhull winter wheat varieties grown in soils of high and low fertility levels.**

Variety	Water in green tissue, %		Milligrams water per gram dry tissue						Difference	Odds
			Total		Free		Bound			
	High	Low	High	Low	High	Low	High	Low		
Blackhull	82.55	81.24	4.730	4.331	3.306	3,135	1.424	1,196	1.31 399 171 228	>99:1 >99:1 1:1 1:1
Minhardi..	82.01	79.53	4.565	3,889	3.334	2,666	1.231	1.223	2.48 676 668 8	>99:1 >99:1 >99:1 1:1
Difference	.54	1.71	165	442	-28	469	193	-27		
Odds.......	1:1	>99:1	49:1	>99:1	<1:1	99:1	<1:1	<1:1		

*Both the high and low fertility soils were taken from fields upon which crop rotations were established in 1903 The rotation is corn, oats, clover, and wheat on the more fertile soil, and corn, corn, corn, and soybeans on the less fertile soil. The better rotation has also received phosphate and limestone Both soils are classified as Carrington silt loam. The above figures are average values of nine samples

Specific conductivity of water extracts and amount and state of water in field grown leaf tissue of Minhardi and Blackhull were compared to crown tissue. Significant differences were found in specific conductivity of water extracts between frozen and subsequently thawed leaf and crown tissue. Specific conductivities of extracts of leaves from field grown Minhardi and Blackhull winter wheat varieties were greater than water extracts of frozen crowns (Tables 3 and 4; also Fig. 2). Individual 1-, 2-, and 4-gram samples were used in one test and the leaves showed greater conductance of electrical current than the crowns in each case (Table 3). Specific conductivity of duplicate samples of water extracts of unfrozen leaves of Blackhull was not significantly greater than of unfrozen crowns (Table 4, Fig. 2). This indicates that specific conductivity is directly related to and dependent upon injury sustained by the tissues as a result of freezing and is not solely dependent upon differences in amounts of minerals present in the tissue. Bose (1) found that freezing temperatures greatly increased the conductivity of cell tissue. Specific conductivities of water extracts of leaves and crowns of Blackhull were significantly greater than those of frozen leaves and crowns of Minhardi, which indicates greater injury to Blackhull as a result of freezing.

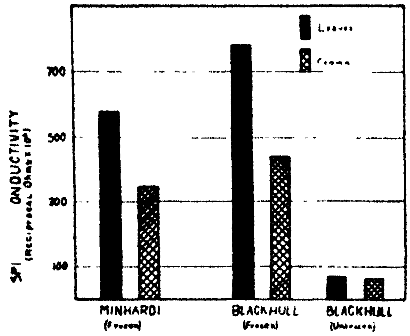

FIG. 2.—Specific conductivity of distilled water extracts of frozen and subsequently thawed leaves and crowns from Minhardi and Blackhull winter wheat varieties and of unfrozen leaves and crowns from Blackhull winter wheat. (See Table 4.)

TABLE 3.—*Specific conductivity of distilled water extracts of frozen and subsequently thawed crowns and leaves from Minhardi and Blackhull winter wheat varieties using 1-, 2-, and 4-gram samples.**

Size of sample in grams	Specific conductivity (reciprocal ohms x 10^6)			
	Leaves		Crowns	
	Minhardi	Blackhull	Minhardi	Blackhull
1	769	818	340	430
2	915	1,020	418	742
4	—	2,005	—	979

*Collected in field at 4:00 p.m. on January 28, 1933, washed in distilled water, superficially dried, placed in closed containers at 2° C for 3 hours to allow excess moisture to become uniformly distributed, placed in freezing chamber at −20° C for 10 hours, 8-hour diffusion period at 2° C in 25 ml of H_2O. Ground was freezing at the time samples were collected. Air temperature was 30° F. Mean daily temperatures were below freezing for the two consecutive days previous to the collection of the samples.

Significant differences were also found in the amount and state of water in crowns compared to leaves. Total water content of the

TABLE 4.—*Specific conductivity of distilled water extracts of frozen and subsequently thawed leaves and crowns from Minhardi and Blackhull winter wheat varieties and of unfrozen leaves and crowns from Blackhull winter wheat.**

Treatment	Average specific conductivity (reciprocal ohms x 10^6)			
	Leaves		Crowns	
	Minhardi	Blackhull	Minhardi	Blackhull
Frozen	574	781	347	442
Unfrozen	—	71	—	66

*Collected in field at 4:30 p m. on February 2, 1933, washed in distilled water, superficially dried, placed in closed containers at 2° C for 3 hours for excess water to become uniformly distributed, duplicate 2-gram samples placed in freezing chamber at -20° C for 10 hours, 8-hour diffusion period at 2° C in 25 ml of H_2O. Air temperature was 33° F at the time samples were collected. The mean daily temperature during the day was 30.8° F.

crowns of both Blackhull and Minhardi was greater than the water content of the leaves (Table 5, Fig. 3). This excess water in the crowns as compared to the leaves existed as free water in Blackhull while much of the excess water in Minhardi crowns existed as bound water. Crowns of Minhardi contained more than twice as much bound water as the leaves. The reverse relation existed in Blackhull. This may help to explain the greater resistance of Minhardi as compared to Blackhull. These results emphasize the need for more consideration of crown tissue in studying cold resistance of wheat varieties. Martin (7) found more than three times as much bound water in the juice of the crowns and roots as in the juice of the leaves of Minhardi.

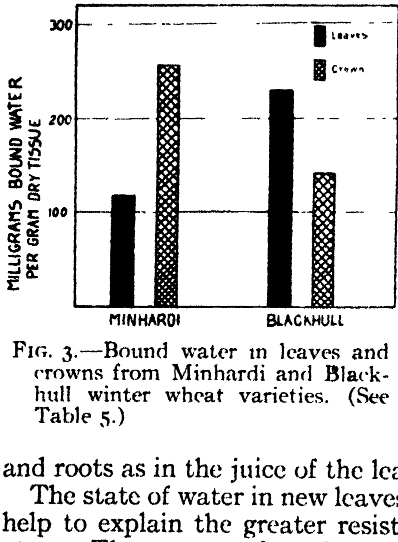

FIG. 3.—Bound water in leaves and crowns from Minhardi and Blackhull winter wheat varieties. (See Table 5.)

The state of water in new leaves as compared to old leaves does not help to explain the greater resistance of new leaves to low temperatures. The amount of total and free water was greater in new leaves of Turkey Red on April 14 after new growth had started in the spring of 1932 than in old leaves. No significant difference was found in bound water content. Average values obtained from 14 samples were as follows:

	Water, %	Mg water per gram dry tissue		
		Total	Free	Bound
New growth	72.27	2,612	2,098	51
Old growth	70.49	2,397	1,878	52
Difference	1.78	215	220	− 1
Odds	99:1	99:1	99:1	2:1

TABLE 5.—*Total, free, and bound water in leaves and crowns from Minhardi and Blackhull winter wheat varieties.**

Variety	Water in green tissue, %		Milligrams water per gram dry tissue						Difference	Odds
			Total		Free		Bound			
	Leaves	Crown	Leaves	Crown	Leaves	Crown	Leaves	Crown		
Blackhull . . .	76.65	80.90							– 4.25	>99:1
			3.286	4.249					– 963	>99:1
					3.056	4,107			–1,051	>99:1
							229	142	87	1:1
Minhardi	74 20	76.03							– 1.83	19:1
			2,864	3,185					– 321	49:1
					2,752	2,930			– 178	1:1
							113	256	– 143	19:1
Difference.	2 45	4.87	422	1,064	304	1,177	116	–114		
Odds.	>99:1	>99:1	>99:1	>99:1	>99:1	>99.1	1:1	1:1		

*Plants collected in field at 4.30 p.m. on February 2, 1933, washed in distilled water, and superficially dried, placed in closed containers at –2° C, for 3 hours to permit excess moisture to become uniformly distributed With the exception of one day, freezing temperatures occurred daily during the preceding 9-day period, although the minimum temperature recorded was only 23° F Air temperature was 33° F at the time samples were collected The above figures are average values of four samples.

TABLE 6.—*Total, free, and bound water in washed and unwashed leaves from Minhardi and Blackhull winter wheat varieties.**

Variety	Water in green tissue, %		Milligrams water per gram dry tissue						Differ-ence	Odds
			Total		Free		Bound			
	Washed	Unwashed	Washed	Unwashed	Washed	Unwashed	Washed	Unwashed		
Blackhull	78.27	75.91	3,621	3,141	2,993	2,632	628	508	2.36 480 361 120	>99:1 >99:1 >99:1 2:1
Minhardi	73.83	70.46	2,819	2,385	2,260	1,991	559	394	3.37 434 269 165	>99:1 >99:1 >99:1 >19:1
Difference	4.44	5.45	802	756	733	641	69	114		
Odds	>99:1	>99:1	>99:1	>99:1	>99:1	>99:1	1:1	1:1		

*Plants collected in field at 9:30 a.m. on March 5, 1933, washed in distilled water, superficially dried, placed in closed containers at −2° C, for 3 hours to permit excess moisture to become uniformly distributed. Freezing temperatures occurred daily during the preceding 9 days. The ground was partly frozen when the samples were collected. Air temperature was 35° F. The above figures are average values of seven samples.

Total and free water content both of Minhardi and Blackhull was increased thru increased hydration of the tissues as a result of washing in distilled water (Table 6). The bound water content of Blackhull was not significantly changed, while the bound water content of Minhardi, a hardy variety, was significantly increased as a result of the increased hydration of the tissues.

SUMMARY

1. Relation of free water, the amount frozen at —20° C, and of bound water, the amount unfrozen at —20° C, to cold resistance of winter wheat was studied.

2. Specific conductivity of water extracts of frozen and subsequently thawed tissue was used as a measure of the soluble minerals released from the cells as a result of injury due to freezing.

3. Low total water, low free water, and high bound water of leaves of field grown winter wheat varieties were not consistently related to their known resistance to low temperatures. However, two varieties which differ widely in known resistance showed consistent differences in total and free water content. Leaves from Minhardi, a hardy variety, contained less total and less free water than leaves from Blackhull, a less hardy variety. No consistent differences in bound water were found even in leaves of Minhardi and Blackhull.

4. Total water in leaves from Minhardi and Blackhull winter wheat varieties grown in the greenhouse in soils of low and of high levels of fertility was greater in plants grown in the soil of high level of fertility. Differences between the amounts of free and bound water were not consistent.

5. Crown tissue of winter wheat varieties should receive more consideration than leaf tissue in testing cold resistance of winter wheat varieties. Soluble minerals measured by electrical conductivity in water extracts of frozen leaves from Minhardi and Blackhull winter wheat varieties were greater than in water extracts from frozen crowns. This indicates greater injury to leaves from freezing at —20° C. The amount of total and free water in both varieties was also greater in the crowns than in the leaves. The amount of bound water was more than twice as much in the crowns as in the leaves of Minhardi. The reverse relation was found in Blackhull, although the difference was not significant.

6. Greater cold injury to both leaf and crown tissue when exposed at —20° C was found in Blackhull than in Minhardi.

7. Total and free water content both of Minhardi and Blackhull leaves were increased by washing. Bound water content of Minhardi was increased slightly more than the bound water content of Blackhull through increased hydration of tissues from washing.

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NATIVE GRASSLANDS IN THE HURON (SOUTH DAKOTA) AREA[1]

V. H. FLORELL[2]

THE greater part of the land in eastern South Dakota is under cultivation. Crops have been grown on some of it for 50 years or more, and the remainder has been broken up more or less gradually. During the period of the World War a great impetus was given to breaking much of the remaining prairie sod, due especially to the great demand for wheat. A casual observer might get the impression that practically all of the land in this part of the state is under cultivation. While this is hardly the case, nearly all land suitable for cultivation, and some not suitable, has been broken up. Some of the most serious erosion problems occur on the latter type of land. Interest in virgin areas has been greatly increased during the last few years due to their resistance to erosion by both wind and water. In order to determine the approximate amount and distribution of native sod in this section of South Dakota, the condition of present grass stands, and to get additional information on the distribution of the predominating grasses and weed plants, a survey of a fairly large acreage of land was undertaken

The Wolsey and Shue Creek Soil Conservation Demonstration areas near Huron were utilized for the study which was carried on during late winter and spring of 1936. The Shue Creek area contains about 144,000 acres and is located east of the James River, principally in the east-central part of Beadle County Its northeastern part includes the extreme southeast corner of Spink County and a part of southwestern Clark County Originally this demonstration area was supposed to include the watershed of Shue Creek, but later additional territory to the south was included.

The Wolsey area is located in the western part of Beadle County and extends in a northwest and southeast direction Cain Creek runs along its border on the west, both north and south, and traverses a part of the west-central portion. Forty-six thousand acres are included in this area

METHODS OF MAKING SURVEY

A map with numbered sections, townships, and ranges was used in making the survey. An automobile speedometer sensitive to one-tenth mile was used for measuring distances. The project areas were traversed from east to west, and

[1]Contribution from the Soil Conservation Service, U. S Dept. of Agriculture. Received for publication February 23, 1937.

[2]Associate Agronomist. The writer wishes to express appreciation to the following members of the Soil Conservation Service staff at Huron, South Dakota, for collaboration and assistance in various phases of this study · C. O. Stockland, Assistant Soil Surveyor; Eugene Swift, Junior Soil Expert, and L. E. Johnson, Junior Soil Surveyor, for assistance in the early stages of the reconnaissance survey; and to O. P. Drake, Junior Agricultural Engineer, for assistance in the preparation of the base maps and for aid in making the detailed survey of grasslands as to condition.

from north to south on section lines so that all four sides of each section were examined. The limits of pasture and hay lands were determined to one-tenth mile (and fractional tenths by interpolation) by means of the speedometer and carefully entered in colored pencil on the maps. The work maps were checked later with the project aerial photographic maps which were invaluable in properly delimiting the grass tracts.

In the field, grasslands in good condition were easy to distinguish. In cases of hard usage some difficulty was experienced. Only those were considered virgin areas which still had a fairly good stand of the native short grasses, especially the grama species. It was found that lands which have been under cultivation and were later permitted to lie idle had a definite tendency to go back to grass. Recently cultivated lands, now idle, apparently are making a very slow return to grass, due primarily to the prolonged drought. The principal grass which is found under these conditions is western wheatgrass, *Agropyron smithii*. For this reason farmers usually speak of it as "go-back grass". The grama grasses apparently reestablish themselves with considerable difficulty.

In doubtful cases all grasslands were examined physically, including those where pastures and meadows were invisible from the section lines beyond cultivated fields. Land showing indications of disturbance by cultivation in years gone by, although now used for pasture, was not mapped (Only a low percentage of good re-established grassland of the total native grass area would come under this classification.)

COMPARATIVE AREAS OF PASTURE LAND AND CULTIVATED LAND

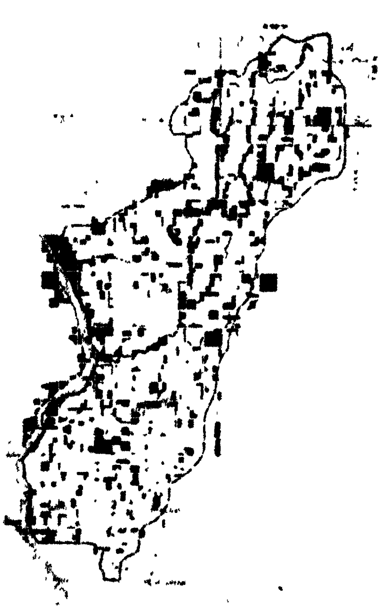

FIG. 1.— Map showing tracts of native grassland in the Shue Creek Demonstration area, Beadle County, South Dakota.

The maps in Figs. 1 and 2 show the distribution of grasslands in the Shue Creek and the Wolsey Demonstration areas. The grass tracts appear in black. The approximate percentages of native grassland in the Shue Creek and Wolsey areas are 21.9 and 27.5, respectively.

It may be noted that most of the grass acreages are located along the streams. The reason for this is obvious, as such land often is rough and stony and not suited for cultivation. School lands represent the next largest source of grass. In this part of South Dakota quite a number of school sections still remain, but where the soils are especially desirable they have been sold and the land put under the plow.

One fact emphasized by the survey is that very little grassland is found on certain soil types. The Barnes silty loam,

clay loam, and clay and the Sioux loam usually are mostly or nearly all cultivated. A somewhat larger proportion of grass occurs on Barnes loam. A fairly large amount of grass occurs on the Beadle silt loam. The Lamoure clay and its poorly drained phases occurring along stream lowlands are almost all in grass. Likewise, the Lamoure silt is in grass for the most part although in certain locations it is a valuable cultivated soil.

PRESENT CONDITION OF VIRGIN LAND

Practically all of the remaining virgin lands are used for pasture or hay meadow. These are in best condition on hay meadows as would be expected. In general, hay meadows on school lands are in better condition than hay meadows on farms The grass areas in next best condition are found in pastures on school land and on privately owned land along streams, although private pastures here, as elsewhere, often have been given severe usage. Fig. 3 shows a general view of the character of good pasture on school lands; and Fig. 4 a fairly good, though heavily used, pasture on land along one of the larger creeks. Pasture land on school sections is in fair to fairly good condition in most cases. On the average, farm pastures on good productive land are in the poorest condition. These usually consist of comparatively small areas located near farm buildings. The usual practice has been to put all the animals on each farm into one pasture. In many cases the native stands of grass have been almost completely killed and have been replaced by Russian thistles which are found in great abundance wherever a possibility for foothold presents itself. Fig. 5 gives a general view of a heavily used pasture whose native grasses have been replaced almost completely by Russian thistles. Fig. 6 gives a view of a meter quadrat showing the scattered stand of short grass (Grama) remaining on parts of this pasture.

FIG. 2.—Map shows tracts of native grassland in the Wolsey Demonstration area, Beadle County, South Dakota.

Other areas used for pastures are stony land or low places where water collects. and the borders of shallow lakes. In later years many of the lakes have dried out and in most cases are overgrown with weeds.

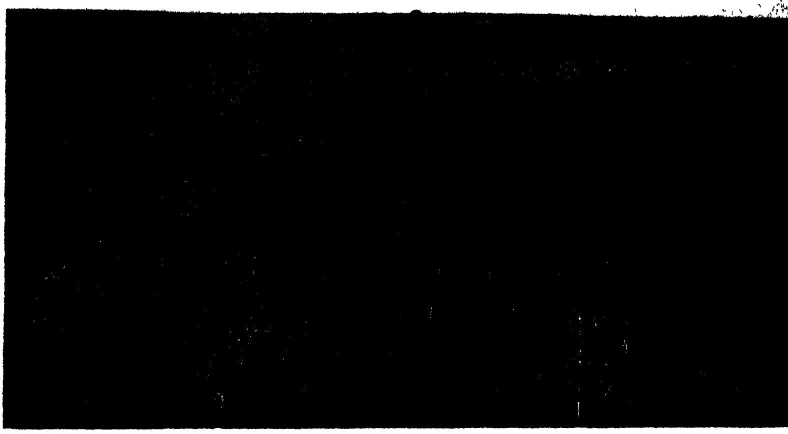

FIG. 3.—General view in early spring of good native sod on a school section.

Only a part of the total grasslands have been examined closely as to condition at the present time. In this work, which was done in June 1936, each pasture was classified as to the average percentage stand of grass. Notations were made as to the present condition and usage, with a list of the predominating species of grass and important pasture weeds. The data collected, although limited, should give a fairly definite idea as to the present condition.

Fifty different pastures located in four different townships in the Shue Creek area, with a combined area of approximately 4,125 acres, were surveyed carefully as to condition. Twenty-seven per cent of this acreage was classified as good, with an estimated grass crown

FIG. 4.—General view in early spring of pasture lands along Shue Creek.

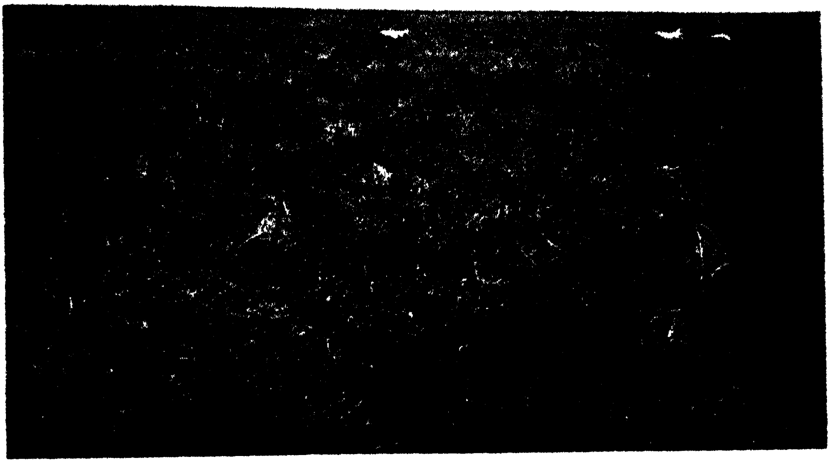

FIG. 5.—General view in early spring of a heavily used pasture almost entirely overgrown with Russian thistle.

coverage of 45 to 60%; 19% fair, coverage 30 to 45%; 45% poor, coverage 15 to 30%; and 9% very poor, coverage 0 to 15%. Thus, on this basis, over 50% of the pasture acreage surveyed is in poor to very poor condition. The ability of the poorest of these pastures to recover in a reasonably short time is very doubtful.

PREDOMINATING NATIVE GRASSES

The vegetation of special interest in this study are the grasses, the distribution of which varies considerably with the location. Blue

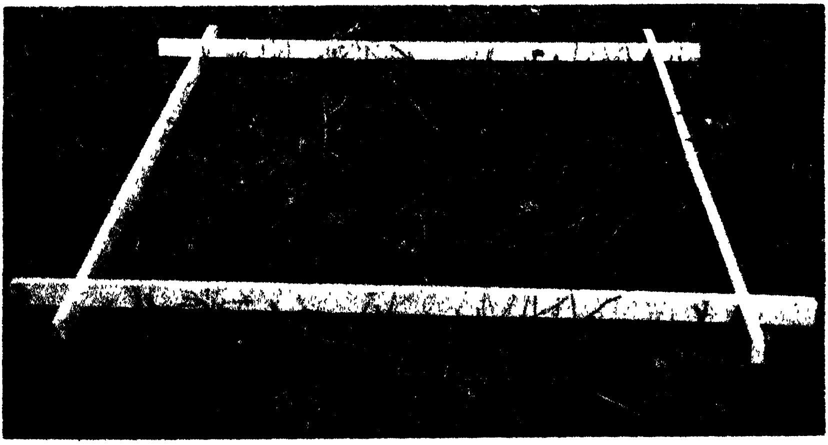

FIG. 6.—View of meter quadrat showing the stands of short grass remaining on the better parts of the pasture shown in Fig. 5. The scattered stand of grama grass appear as whitish tufts. All other perennial grasses have dis appeared.

grama (*Bouteloua gracilis* Lag.) and western wheatgrass (*Agropyron smithii* Rydb.) are the most important species. On prairie lands which have not been too severely grazed western wheatgrass is prominent. This species usually is interspersed with a more or less dense stand of grama. Grama is best adapted to the drier soils and apparently it also stands severe usage better than western wheatgrass.

Buffalo grass (*Buchloë dactyloides* Nutt.) is found in scattered patches, but it is less common than the grama. Big bluestem (*Andropogon furcatus* Muhl.) occurs in occasional patches on moist, fertile soils, and likewise little bluestem (*Andropogon scoparius* Michx.) on dry knolls and slopes. On the average, the population of bluestem grasses is small.

Caird,[3] in an ecological survey in connection with range management work, lists the above-mentioned species, with the exception of little bluestem, as the chief grasses of the area.

Western wheatgrass when occurring in more or less pure culture usually is found on the prairie lowlands. (Lowland here refers to the low places where water collects after rains and occasional shallow lakes or ponds which are now dry.) Likewise, the most abundant grass on lowlands along the streams is western wheatgrass.

Distichlis stricta, commonly known as "saltgrass", is found in locations where there is a tendency to accumulations of alkali. The largest stands occur along Cain Creek in the Wolsey area. It is found also in certain places in the Shue Creek area and in drainage basins around artesian wells on both areas.

Other fairly common but less useful grasses include needlegrass (*Stipa comata* Trin. and Rupr.), observed in occasional scattered stands on unpastured prairie grasslands, and foxtail barley (*Hordeum jubatum* L.), fairly abundant on the lowlands and more moist locations on grasslands that at some time have been subject to severe usage.

EFFECT OF USAGE ON NATIVE GRASSES

On the prairies, western wheatgrass, the grama grasses, and the bluestems represent climax species under favorable conditions. With heavy usage the tendency is for the western wheatgrass to disappear, leaving the grama grasses and buffalo grass. As the stands are reduced in density weeds invade the grasslands. A very common weed in pastures is gumweed (*Grindelia squarrosa* (Pursh) Dunal.), which is nearly always associated with pastures that have suffered hard usage. Where the grasses and also the gumweed have been killed, peppergrass (*Lepidium densiflorum* Schrad.) and the Russian thistle (*Salsola Kali* L.) usually take possession.

EROSION CONDITIONS

Little or no erosion occurs where the stand of native grass is in good condition. On the heavily used pastures, however, blowing may get started and moving soil will destroy vegetation, thus increasing

[3]Caird, Ralph W. Tendencies in the natural revegetation of wind erosion areas on the northern Great Plains. Amer. Soil Survey Assoc. Bul. 17:132–135. 1936.

the size of the blow areas. A common source of damage to pastures is the deposition of blown soils from cultivated fields. In some locations this is sufficiently severe to destroy the weakened stand of grass. Russian thistles now in most cases have complete possession of such places.

Soil texture has a direct bearing on erosion of the virgin soil land. Pastures on sandy soils that receive hard usage are very susceptible to blowing. On the other hand, where given proper usage, no blowing occurs. On the average, the heavier the pasture soils, the less subject they are to wind erosion.

DISCUSSION

It is evident that grasslands play an important rôle in the control of wind erosion. In addition to being resistant to erosion they provide considerable protection to adjacent cultivated lands. Where wind erosion is troublesome it becomes necessary either to change farming practices by proper use of crop residues, by use of rotation systems, by using different crops, or by extending the use of grass in the farming system. It is very likely that a greater use of grass together with a change in farming practices will be necessary to effect permanent improvement in farming conditions and for the saving of much of our agricultural lands from ultimate destruction by erosion.

Several species of both native and introduced grasses are, or soon will be, available for expansion of the grass acreage in the northern Great Plains region. The principal native species most likely to be used include western wheatgrass and blue grama and the introduced species, crested wheatgrass (*Agropyron cristatum* L. Beauv.), and smooth brome (*Bromus inermis* Leyss).

In order to plan more definitely what percentage of our lands should be in grass, it would be necessary to know how well the change in agricultural practices and the use of rotation systems will function in the control of the problem. Obviously this information will not be available until changes in agricultural practice have first been put into effect. In the meantime, with due consideration for the needs of the individual farmer, it is safe to assume that the acreage of grass should be substantially increased. In general, the economic position of agriculture now is particularly favorable to the return of land to grass.

Expansion of the grass acreage involves two distinct problems, *viz.*, (1) the restoration of pastures and meadows which have been partially or wholly destroyed by heavy usage or by wind erosion and soil deposition, and (2) the establishing of new acreages of native and introduced grasses.

To make existing grasslands fully effective in the erosion control program, depleted pastures must be restored and then maintained by proper pasture management. It is not enough to reseed and restore stands of grass in old pastures. If grass stands are to be maintained and if the greatest net return per acre is to be obtained, attention must be given to correct pasture management. It is safe to say that the net returns on some of the pastures noted in this survey will amount to but a few cents per acre each year.

Animals maintained on this class of pastures must eat Russian thistles and other weeds to survive, but weedy pastures cannot be depended upon in the control of erosion, quite regardless of their undesirability as a source of feed for farm animals.

A substantial return of cultivated lands to grass in this region would go far in the control of wind erosion thus reducing the loss from destructive dust storms which have become common in the Great Plains region during recent years.

Sandy soils and others particularly susceptible to blowing should be returned to grass as soon as possible, and likewise, stony, rough, and relatively unproductive land and fields or parts of fields subject to severe water erosion. Idle land, instead of being permitted to serve as a fertile source of weed seeds of various kinds and a breeding place for grasshoppers, also should be included in the acreages to be returned to grass. During years of good reserve moisture, the seeding of land to permanent grass should be pushed vigorously by farmers, since stands can be established more readily during such seasons.

In addition, wherever the size of the farming unit will permit, a portion of the arable land of each farm might well be kept in grass as part of a long-time rotation, in order to build up soil fertility and soil structure. In virgin fields, according to authorities on soils, the soil particles are held together in aggregates by means of plant rootlets, humus, and partially decayed vegetable remains. Through cultivation, use, and oxidation this structure is destroyed leaving the individual particles susceptible to movement by wind during droughty periods when the land is not provided with plant cover The belief is growing that grass should be left undisturbed for a reasonably long period of years to permit at least a partial restoration of the soil aggregates.

Considering the need for improvement and maintenance of the soil structure of agricultural soils and the prevention of wind erosion in this section, one-third of the land suitable for cultivation might well be in permanent grass. This proportion of the cultivated land in grass would afford a convenient basis for a long-time grass rotation. The section of the state where this would be particularly appropriate, considering erosion conditions, would be west of the 20-inch average rainfall line. This line extends approximately from a point about 50 miles west of the northeastern corner of the state (a short distance east of the 98° meridian), southward about 125 miles, then southwest to a point where the 99° meridian intersects the southern boundary line of the state. The proportion of grass might well be increased westward with a decrease in average precipitation. On this basis, the percentage of an agricultural area devoted to grass would be a third of the land suitable for cultivation, plus the "natural" pasture and hay land.

Perhaps a return of the land to grass to this extent would not meet the needs of a profitable agriculture, or perhaps a greater percentage return would be desirable. The proportion of return to grass suggested, however, presents a goal desirable from the standpoint of the preservation of our agricultural resources.

SUMMARY

The native grasslands in the Wolsey and Shue Creek Soil Conservation Demonstration areas (about 190,000 acres) in Beadle County, South Dakota, were mapped to show their amount and distribution.

The approximate percentage of native sod in the Shue Creek area was 21.9 and in the Wolsey area 27.5.

A sample of 50 pastures in the Shue Creek area, containing about 4,125 acres, was examined in June 1936 for condition. Twenty-seven per cent of the acreage was classified as good, with an estimated grass crown coverage of 45 to 60%; 19% as fair, coverage 30 to 45%; 45% as poor, coverage 15 to 30%; and 9% as very poor, coverage 0 to 15%. The ability of the poorest of these pastures to recover in a reasonable time is doubtful.

The predominating grasses are blue grama and western wheatgrass.

Little or no wind erosion has occurred where the stands of native grass are in good condition.

THE RELATION BETWEEN THE MOISTURE CONTENT AND THE TEST WEIGHT OF CORN[1]

S. R. MILES[2]

THE weight per measured bushel of shelled corn, which is called the test weight, is one measure of quality in corn. It is of little value for comparing varieties or strains of corn but is useful for comparing the same strain under different conditions. Since the test weight varies with the moisture in the grain, it is desirable that samples to be compared for test weight have the same moisture content. Accomplishing this is generally impractical. The practical alternative is to adjust the test weights of samples with different moisture contents to make them comparable. The information necessary to permit such adjustments has not been available. The work reported in this paper had as its object the obtaining of such information.

PROCEDURE

Five varieties of corn which differed widely in their characters were used. These varieties ranged from very early to very late for growing at Lafayette, Indiana. In order of earliness, these varieties were Clement White Cap Yellow Dent, Bryant Reid Yellow Dent, Krug, Purdue 11 Reid Yellow Dent, and Johnson County White Dent. Krug was very different from the other varieties. It had little to no indentation of the crowns of the kernels, the crowns of many kernels were decidedly rounded, and the kernels contained a high proportion of vitreous starch. The other varieties had moderate to fairly rough indentation, were more nearly square at the crowns, and had less vitreous starch, though they varied considerably in these characters. Clement White Cap was most like Krug. Johnson County White was at the other extreme and it had the largest and roughest kernels.

On October 23, 1935, a sample of each variety was husked, shelled, and cleaned on a fanning mill. After cleaning there were 15 to 20 pounds of each variety. The test weight of each was determined and a moisture sample was taken. The grain was then spread in flat trays with wire mesh bottoms to a depth of about 1.5 inches. These trays were placed in a room in which the air was warm and low in humidity. The air could circulate freely through the corn. Daily moisture and test weight determinations were made until both became practically stationary.

A Boerner test weight apparatus with a quart cup was used. Five determinations of test weight were made on each sample each day after thoroughly mixing the sample by pouring from one tub to another several times. The means of five tests were used for the analysis of the results. The quantity of each sample was sufficient to permit making the five daily tests without using the same grain but once.

Till the corn was fairly dry, it sometimes stopped flowing from the hopper of the Boerner apparatus. Flow was again started by punching down through the corn once with a wire or pencil. Sometimes the flow had to be restarted several times before the hopper was empty.

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[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Published with the approval of the Director of the Station. Received for publication February 26, 1937.

[2]Assistant in Agronomy.

Similar tests were begun October 2 and 15, 1936, with each variety and October 8 with one sample of the White Cap. Thus four lots of White Cap and three of each of the other varieties were used, making a total of 16 lots. At the beginning of the tests the samples contained from 24 to 40% moisture with an average of 32%. At the end of the tests the moisture varied from 7 to 10%.

Eight to 13 days were required for the corn to reach a constant test weight depending on the temperature and humidity of the air in the room where the corn was stored.

In 1936, when the test weight became constant, the samples were put into bags which were hung in a slightly heated room. About three months later the corn was tested again. Six lots of corn were then wet thoroughly and quickly drained. The next two days tests were made. Again more water was added and tests made the next two days. Each wetting increased the water content about 5 or 6% so that after the second wetting the corn contained about 20% moisture. So far as indicated by the the test weight, the changes in the kernels due to adding water had been completed within 24 hours after each wetting. Because of this last fact, water was added daily for three days to the other five lots of 1936 corn. The moisture was raised to 24 to 28%.

In 1936, portions of five lots of corn which had not been re-wet were dried for 24 hours in an oven at 102° C and the test weight determined.

PRINCIPAL RESULTS

The discussion of the relation between the test weight and the percentage of water deals with the results from corn being *dried*, except when otherwise noted.

The test weights and the percentages of water were plotted separately for each of the 16 lots of corn. It was found in each case that a smooth curve fitted the data remarkably well. All curves were similar in general shape to the two curves in Fig. 1. As the corn dried from the highest moisture contents, the test weight decreased somewhat. After reaching a minimum, the weight increased with further drying until a maximum test weight was reached at about 10% water. The only striking difference among the curves was in the degree of slope between 10 and 25% water.

Apparently the test weight varies little or none with percentages of water below 10. This was true of the corn which was dried slowly to 7% water and also of the corn dried quickly in the oven. These five lots of corn were dried from an average of 8 5% water to an average of 1.3%. There was a non-significant average decrease of only 0.1 pound in test weight.

Because the test weight reached a maximum at 10% water, the data for all curves were expressed as differences in test weights from those at 10% water. Subsequent calculations used these data.

To compare varieties, an average curve was drawn for each variety. Because it was found that the curves for the four varieties other than Krug were almost identical, an average curve was then drawn for those four varieties. The Krug average curve and also each of the three curves for the individual lots of Krug were steeper than the four-variety average curve. This led to the belief that Krug behaves differently from the other varieties with respect to test weight with changes in moisture content. For this reason, the Krug data were kept separate.

Fig. 1 gives the curves for Krug and for the four-variety average. The corresponding numbers are given in columns 1, 2, and 4 of Table 1. The solid portions of the curves in Fig. 1 are the actual average curves. To the right of the solid curves, data were available from fewer lots of corn and those portions of the curves were actually at

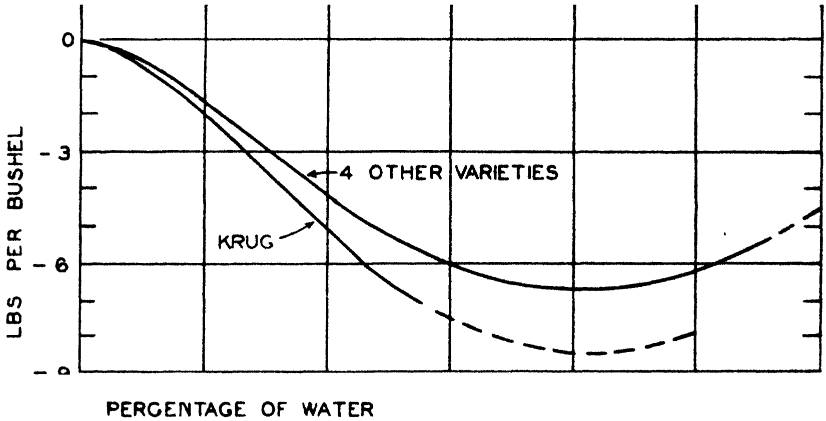

FIG. 1.—Relation between the percentage of water in corn which is drying and the weight per measured bushel. The weights are expressed as differences from the weight with 10% water.

different levels than in Fig 1. In making the curves in this figure, the dotted portions were moved downward, but without rotation, to join the solid curve. This procedure assumes that the shape of the curve in the moisture range of the dotted lines is independent of the general elevation of the curve. This assumption is supported by comparing the dotted portion of the Krug curve with the solid portion of the other curve as well as by comparing the 16 curves for individual lots of corn.

To construct the curves of Fig 1, an average test weight for each unit of water was calculated from the curves for the individual lots of corn. The fit of the four-variety curve was so good that of the 28 points from 11 to 38% water only 5 appeared to be off the curve. These were all at or beyond 29%, where the data were fewer. No point was more than 0.2 pound off the curve. The Krug curve fit even better.

Table 2 gives some regression coefficients for the curves of Fig. 1. It shows that in the range of 8% water from 14 to 22%, the curves are very nearly straight. The difference in steepness of the two curves is shown by the fact that in this range the test weight of Krug increases 0.59 pound for each decrease of 1% water whereas the corresponding figure for the four-variety average is only 0.48 pound. Over a 13% range from 12 to 25% water, the curves are fairly straight. In this range, the average change in test weight for each per cent of water is 0.53 pound for Krug and 0.43 pound for the four-variety average. Table 1 and Fig. 1 show that the test weight was lowest when the corn contained about 30 or 31% water.

TABLE 1.—*Differences between the test weight of corn with 10% water and with greater percentages of water.*

Percentage of water	Four-variety average*		Krug	
	Differences, lbs.	Standard errors,† lbs.	Differences, lbs.	Actual standard error, lbs.
11	-0.1	0.06	-0.2	0.07
12	-0.4	0.13	-0.5	0.07
13	-0.8	0.21	0.9	0.07
14	-1.1	0.29	1.3	0.07
15	-1.6	0.37	-1.9	0.10
16	-2.0	0.44	-2.5	0.16
17	-2.5	0.52	-3.1	0.12
18	3.0	0.60	-3.7	0.10
19	3.5	0.68	-4.3	0.20
20	4.0	0.75	-4.9	0.31
21	-4.5	0.83	-5.5	0.44
22	5.0	0.91	-6.0	0.64
23	5.4	0.99	-6.6	0.93
24	5.7	1.06	-7.0	1.16
25	-6.0	1.14	-7.4	—
26	6.2	1.22	-7.7	—
27	-6.4	1.30	-7.9	—
28	6.5	1.37	-8.1	—
29	-6.6	1.45	-8.2	—
30	6.6	1.53	-8.3	—
31	-6.7	1.86	-8.3	—
32	-6.6	0.44	-8.2	—
33	-6.5	0.63	-8.1	—
34	-6.3	1.71	-8.0	—
35	-6.1	0.90	-7.8	—
36	-5.8	1.23	—	—
37	-5.5	1.02	—	—
38	-5.2	0.83	—	—
39	-4.9	0.50	—	—
40	-4.5	0.30	—	—
Average test weight with 10% water	57.4	—	61.9	—

*Clement White Cap yellow dent, two strains of Reid yellow dent, and Johnson County White dent

†Smoothed standard errors from 11 to 30%, actual standard errors from 31 to 40%.

It is worth while to make some comparisons among the 16 curves for the individual lots of corn. The slopes of these curves varied considerably even within a variety. For each variety, the test weight differences at 10% water were greater—usually much greater—than the differences among the lowest test weights for the same lots of corn. This fact is brought out clearly by Table 3. In other words, the higher the test weight at 10% water, the steeper the curve. This is true with-

TABLE 2.—*Regression coefficients of test weight on per cent water.*

Portion of curve	Range %	Range limits %	Regression coefficients	
			Four varieties, lbs.	Krug, lbs.
Nearly straight	8	14 to 22	−0.48	−0.59
Fairly straight. ..	13	12 to 25	−0.43	−0.53

in varieties and also between the Krug average and the four-variety average, but it is not true among the four individual variety average curves for the varieties other than Krug. It is concluded that, for comparisons among lots of corn, it is best for the corn to contain less than 15 (or 20) % water when tested, and there is little to gain from making comparisons between lots with over 25% water.

TABLE 3.—*Extreme differences between test weights at 10% water and between the lowest test weights for the same lots of corn by varieties*

Varieties	At 10%, lbs.	At lowest test weights, lbs.
White Cap.	4.7	0.5
Bryant Reid	1.5	1.0
Purdue 11 Reid	3.0	1.5
Johnson County White	5.7	2.7
Krug.	2.7	0.0

Boerner[3] published a curve showing the results of work similar to that here reported. He used only one lot of corn and dried the corn gradually from 19 to 10% moisture. The curve of least slope in the present study was one for a lot of Johnson County White Dent. It was almost identical with Boerner's curve. Phillips and Boerner[4] presented a chart showing the relation between moisture content and test weight of corn for 166 cars from 92 shipping points in Indiana and Illinois for December 1910 and January 1911. The moisture ranged from 16 to 24%. A curve constructed from their data fell between the two curves in Fig. 1.

The stage of development reached by the corn, as measured by the percentage of water at husking, seemed to have no effect on the shape of the curve nor on the test weight with 10% water.

Standard errors of estimate at each unit of water were calculated from the 16 individual curves. These are given in Table 1, columns 3 and 5. As would be expected, the standard errors increased with the distance from 10% water. For the four-variety average, the increase was so uniform to 30% water that smoothed values were calculated. These differed from the actual values by an average of only 0.02 pound, with a maximum difference of 0.05 pound. The values in

[3]BOERNER, E. G. Improved apparatus for determining the test weight of grain, with a standard method of making the test. U. S. D. A. Bul. 472. 1916.

[4]PHILLIPS, C. LOUISE, and BOERNER, E. G. Test weight per bushel. U. S. D. A. Bur. Agr. Econ., Grain Investigations. Mimeographed.

column 3 of Table 1 are smoothed values from 11 to 30% water. The other values in column 3 and all values in column 5 are the actual values. The increase in actual values was not uniform for Krug but nearly all the standard errors for Krug are considerably lower than for the other varieties.

Because the errors of estimate increase with the moisture difference for which adjustment in test weight is made, it is desirable to have the moisture range as small as possible for the lots of corn to be compared. For the same reason, it is also best to make all adjustments to the average percentage of moisture of the lots.

The relation between test weight and percentage of water was found to be very different when water was added to the corn than when the corn was drying. Again Krug was found to behave differently from the other four varieties. In all cases, the changes in test weight associated with changes in water content were much greater when water was added. The average change was 139% as much for the four varieties and 159% as much for Krug. The ranges in change were from 120 to 153% for the four varieties and from 128 to 173% for Krug. Each comparison was made for the same lot of corn between the relation when it was drying and the relation when it was being wet periodically.

Five lots of the re-wet corn were re-dried to below 10% water in about 4 days. The test weights after re-drying were 2.8 to 5.7 pounds lower than with the same water content before re-wetting. In general, the differences were smaller for the two smoother varieties and greater for the three more roughly dented varieties. It appears that the changes in the corn caused by wetting are not entirely reversed upon re-drying.

OTHER RESULTS

In the three months from October, 1936, to January, 1937, while the corn was hanging in bags, the 11 lots of corn dropped an average of 1.2% in moisture—from 9.9 to 8.7%—though the difference is not statistically significant. The test weight dropped an average of 1.08 pounds with high odds for a drop of *at least* 1.00 pound In view of results previously given, this change in test weight was probably not due to a change in moisture. Apparently during storage some change took place other than in moisture and affected the test weight.

The average test weights, in pounds per bushel, of the five varieties at 10% water were: Krug, 61.9; Clement White Cap, 58.8; Bryant Reid, 57.8; Purdue 11 Reid, 57.3; and Johnson County White, 55.3. In general, test weight increased with smoothness of indentation.

Corn grown on the dark Brookston silt loam and Clyde silty clay loam weighed about 2 pounds more per bushel than corn grown on the lighter colored, and generally less productive, Crosby silt loam.

The standard deviation of individual determinations of test weight in corn was found from 328 degrees of freedom to be 0.243 pound. On this basis, a difference of about 0.6 pound between individual determinations is needed for significance and about 0.8 pound for high significance. Between means of five determinations, a difference of 0.25 pound is needed for significance and 0.36 pound for high significance.

The percentage of water in the corn had a striking effect on the number of times that the corn in the hopper of the test weight apparatus had to be punched with a wire or pencil before all the corn would flow from the hopper. Johnson County White corn gave more trouble from bridging in the hopper than the other four varieties. Table 4 gives the results of this study. Only corn with less than 16% water flowed from the hopper with practically no punching.

TABLE 4.—*Average number of punches required to cause all corn to flow from the hopper of the Boerner test weight apparatus.*

Water in the corn, %	Number of punches required	
	Johnson County White Dent	Four other varieties
11-15	0.04	0.04
16-18	1.0	0.2
19-21	4.4	0.6
22-24	4.1	2.6
25-27	9.2	4.5
28-30	7.9	5.2
31-39	9.2	7.2

SUMMARY

Sixteen lots of five varieties of corn were tested daily while drying in a warm room to determine the relation between the weight per measured bushel and the percentage of water. The relation was somewhat different for Krug and the other four varieties. The association was negative in the range from 10 to about 30% water. In the range from 14% to 22% water, the association was practically linear, and for each change of 1% in the water Krug changed 0.59 pound and the average change of the other four varieties was 0.48 pound per bushel.

The detailed results permit adjustments to improve comparisons of test weights of lots of corn with different moisture contents.

It is best for the corn to contain less than 15 (or 20)% water when tested and there is little to gain from making comparisons between lots with over 25% water.

Because the errors of adjustment increase with the moisture differences, it is desirable to have the moisture range as small as possible for the lots of corn to be compared. In addition, it is best to make all adjustments to the average percentage moisture of the lots.

When water was added to corn, the changes in test weight associated with changes in water content were much greater than when corn was drying.

The standard deviation of individual determinations of test weight in corn was found to be 0.243 pound. For significance with this standard deviation, individual test weights must differ by 0.6 pound and means of five determinations by 0.25 pound.

NOTES

A SEED DROPPER FOR CEREAL NURSERY ROWS[1]

THE seed dropper described here has been adapted from the chain-drive model of the Columbia planter that has been on the market for several years. It was rebuilt by the instrument shop at the Iowa State College at a cost of approximately $16.00. (See Fig. 1.)

The tool consists of a belt operating in the bottom of a trough, with an adjustable gate that may be set for different row lengths. The ratio of speed of the seed belt to that of the drive wheel is approximately 1:12, but the dropper needs calibrating for each length of row.

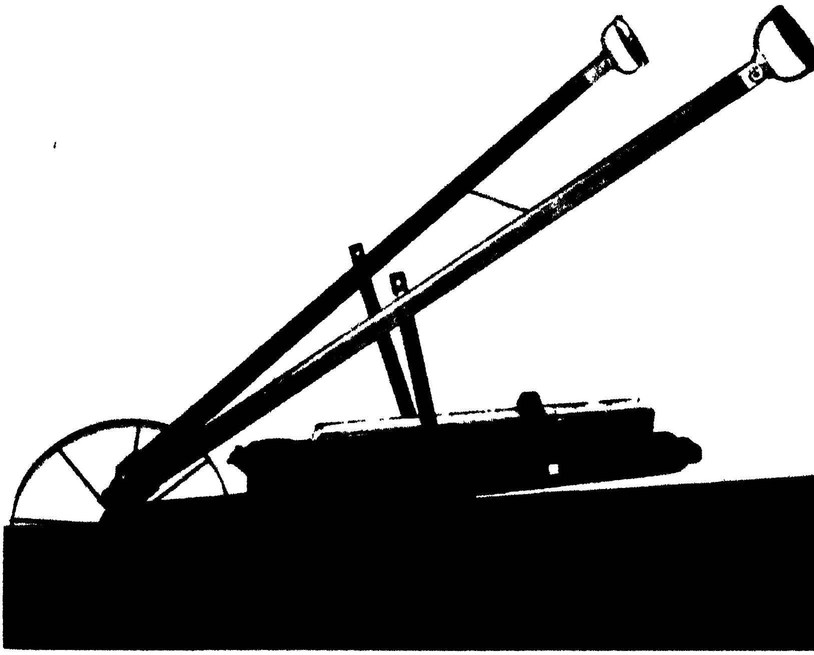

FIG. 1.—A seed dropper for cereal nursery rows.

The speed with which the dropper can be operated depends upon the ability and experience of the operator and the weather conditions under which he must work. In the hands of a skillful operator, using wheat for seed and working under good weather conditions, 150 rows per hour is not impossible. With no previous experience, three workmen averaged 70 rows per hour for their first day's work on a nursery that had been previously marked and the seed packets distributed to the plats. Experienced operators, using oats, barley, wheat, and flax will average from 90 to 100 rows per hour in good weather. When the wind is high or if the seed is very light, the sowing will be slowed down considerably. The dropper can be used in higher wind velocities than are permissible for hand sowing.

[1]Journal Paper No. J441 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 144.

In operating the dropper efficiently it has been found desirable to use 4-foot alleys between the ranges, sowing from center to center of the alleys. There is a lag in starting that is not always taken up in the narrower alleys generally used. We have been fairly successful with the allowance of 24 inches at each end of the row. When the seed is all sprouted, guide wires are stretched and the alleys cleaned with a wheel hoe.

The advantages that have been found for the seed-dropper over hand sowing are, (1) economy of not requiring the opening of furrows nor the subsequent covering of the seed; (2) all the seed is sown in moist soil instead of dry furrows; and (3) greater uniformity of depth and distribution throughout the row.—L. C. BURNETT, *Iowa Agricultural Experiment Station, Ames, Iowa.*

INDEX BOARD FOR LABELING PHOTOGRAPHS

THE old Chinese proverb, "A good picture tells more than a thousand words", suggests the value which photographic records may have in helping the plant breeder to maintain a certain parental type through subsequent generations of selection. An index board for labeling photographs of grass selections (Fig. 1) was constructed and used at Tifton, Georgia, last season. While not suitable to all types of work, such a labeling device does minimize the labor required in making photographic records of plant selections.

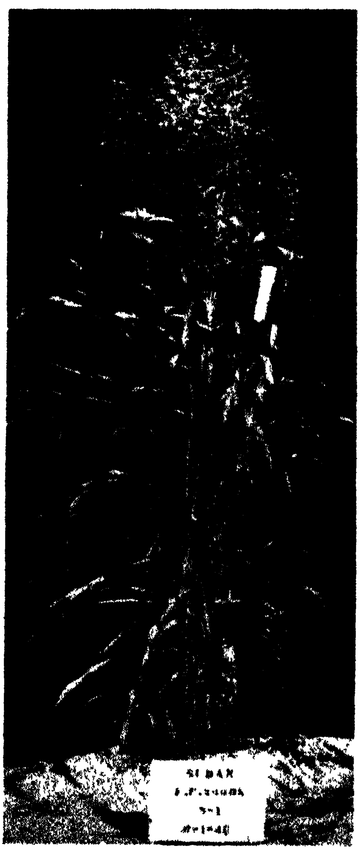

FIG. 1.—Use of index board for labeling photographs of Sudan selections.

In using this device for labeling photographs it was found that when several photographs were taken at one time, written records of the identity of each plate were unnecessary. Much time is saved also in following through the subsequent stages of developing, printing, and indexing negatives. Every negative in which the index board appeared was permanently and accurately indexed.

The construction of the index board, as shown in Fig. 2, is simple. The dimensions indicated in the drawing might well be altered to suit the needs of the individual. Slots in which to slip the letters or numerals were made by nailing strips of 28-gauge sheet iron over narrow strips of cardboard so that slots ¼ and ⅛ inch deep were formed

at the lower and upper edges, respectively. Three-quarter inch letters and numerals were stenciled on heavy manilla folders. By fastening the stencils together in strips, straight rows of properly spaced letters could be made. Strips 1½ inches wide, in which the rows of letters were centered, were then cut from the folders. These strips were finally cut into small sections each containing one well-spaced letter.

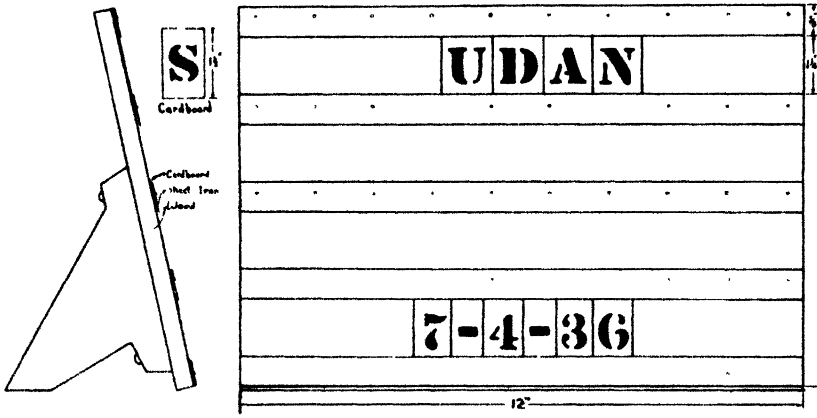

FIG. 2.—Index board for labeling photographs.

The letters and numerals were separated and indexed by placing them in small 2¼ X 3½ inch seed packets from which the flaps had been removed. An identifying letter was printed on the upper left-hand corner of each packet. All packets were then arranged in alphabetical order in a small filing box. This facilitated the finding of any desired letter or numeral as required.—GLENN W. BURTON, *U. S. Dept. of Agriculture, Tifton, Ga.*

A RAPID QUANTITATIVE METHOD OF STUDYING ROOTS GROWING UNDER FIELD CONDITIONS

A RAPID and quantitative method of studying root activity has been designed. This method, originally described by Sprague[1], has been modified and improved by the writer. The method is particularly desirable because a large volume of work can be done at minimum expense.

The tools used for obtaining soil prisms are shown in Fig. 1 and the method of manipulation is demonstrated in Fig. 2. The heavy iron wedge-shaped tool on the left in Figs. 1 and 2 has a straight blade 12 inches long, 7 inches wide, and ½ inch thick at the upper end, tapering gradually to the cutting edge. This special tool was used to make a rectangular opening in the sod to the full depth of the blade. Soil prisms approximately 3 inches x 7 inches x 12 inches were cut and removed from the rectangular opening.

[1]SPRAGUE, H. B. Root development of perennial grasses and its relation to soil conditions. Soil Science, 36:89–209. 1933.

In order to remove the samples with ease and without damaging the surrounding sod and roots, the special tool on the right in Figs. 1 and 2 was designed. Fig. 1 shows the hinge attachment and the beveled edges on the tools and Fig. 2 shows the principle of operation, which resembles that of a post-hole digger. The tool for removing the

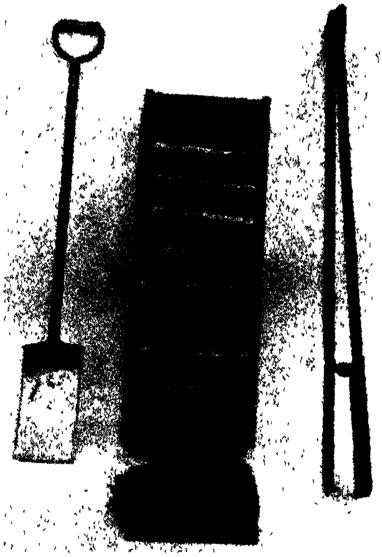

FIG. 1.—Iron tools for obtaining soil prisms from the field and a convenient arrangement for conveying samples to the laboratory.

FIG. 2.—Method of operating the tools. The heavy straight-edged iron tool is used to make the rectangular-shaped opening and the hinged tool with beveled edges serves to remove the soil prism from the opening.

soil prisms must be unhinged and introduced into the rectangular-shaped opening previously made with the former tool and then re-hinged for removing the prism. The soil prisms, when removed, are placed on boards which are placed in a box and transferred to the laboratory for washing as shown in Fig. 1.

The soil prisms are carefully trimmed with a sharp knife to a width of 4 inches and a thickness of 1 inch. The ease of trimming the prism obtained from the field to a size of 1 inch x 4 inches x 12 inches is facilitated by a board form, 4 inches wide, to cut the prism to the desired width. A wood framework 4 inches x 12 inches x 1 inch is placed around the prism 4 inches wide and cut to a thickness of 1 inch. The prism obtained from the field is sufficiently large so that duplicate samples can be cut from it. A soil sample may be taken from the trimmed edges for analysis.

The prepared soil prism and the equipment for washing the roots free from soil is shown in Fig. 3. The soil prism is placed in the open wood form having a screen bottom with cross pieces studded with shingle nails to hold the roots in place. The trimmed prism in the

wooden form is covered with a coarse wire screen and washed free of soil with a fine high-pressure spray. After the roots are free of soil the form is inverted and the roots washed on the wire screen, as shown on the right of Fig. 3. The roots washed free of soil may be placed on a board and sectioned to correspond with various soil levels to determine relative distribution of the roots at various depths.

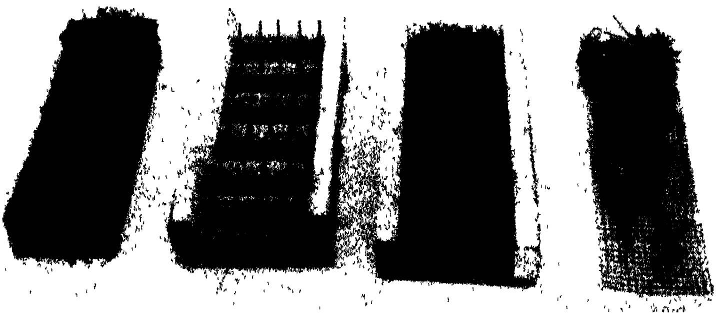

FIG. 3.—The equipment for washing the roots free of soil.

The advantages of this method are as follows. (1) Quantitative results are obtained. (2) With a rapid method it is possible to work with replicated samples. (3) The method may be used for obtaining material for root reserve analysis. (4) The method is especially adapted to soil types which prohibit deep rooting of plants. (5) It is especially useful for studying densely rooted areas, such as pasture sods where individual roots are traced with difficulty. (6) With quantitative methods it is possible to trace the seasonal root-growing cycle. The method has limitations in that samples of the entire root systems of deep-rooting plants cannot be obtained.

With this method it is possible to obtain a large number of soil prisms from the field in a comparatively short time. Under optimum soil moisture conditions two men can obtain as many as 20 samples in an hour. Washing the roots free of soil is completed rapidly, it being possible to wash 10 samples per hour. This method was used in obtaining 840 samples from the field during the last two seasons. The findings of this work are to be published elsewhere.—R. E. BLASER, *Florida Agricultural Experiment Station, Gainesville, Fla.*

BOOK REVIEWS

METHODS OF STATISTICAL ANALYSIS

By C. H. Goulden. Minneapolis: Burgess Publishing Company. Ed. 2. III + 209 pages, illus. Mimeoprint; flexible covers. 1937. $3.00.

THE first edition of this book was reviewed in this JOURNAL, Vol. 28, page 772, 1936. The principal changes in the new edition are a slight expansion of the chapter on the analysis of covariance and an addition of 42 pages to the chapter on the field plot test.

A discussion of confounding in factorial experiments is added to Chapter XI. The method of confounding and recovery of information is discussed and worked problems are used to illustrate the calculations involved.

Methods for testing a large number of varieties receive considerable attention. Two and three dimensional pseudo-factorial and symmetrical incomplete block experiments are discussed in considerable detail. Numerous worked examples illustrate the way in which the plots in such experiments are arranged and the manner in which the results must be analyzed. Since an experiment can often be set up in several different ways, the author's discussion on choosing the best type of incomplete block experiment for a given test is very timely. Incomplete block experiments have excited a great amount of interest during the past two years. The author's discussion of these experimental methods is set forth logically and clearly and yet the practical side is not lost sight of. (F. R. I.)

DRILLING MUD: ITS MANUFACTURE AND TESTING

By P. Evans and A. Reid. London: Inst. Petroleum Technologists. 263 pages, illus., paper cover. 1937. $5.

THIS document constitutes Volume XXXII of the *Transactions* of the Mining and Geological Institute of India and deals chiefly with problems encountered in oil drilling. Much of the volume, however, treats of the physical properties of suspensions of clays, while discussions on viscosity, thixotropy, alkalinity, and acidity will interest soil scientists. The text is well illustrated and many of the experimental data are presented in graphic form. An extensive bibliography and a detailed index add to the usefulness of the volume.

AGRONOMIC AFFAIRS

STUDENT SECTION ESSAY CONTEST

THE American Society of Agronomy is again sponsoring a student essay contest inaugurated a few years ago. Considerable financial assistance from the Chicago Board of Trade makes it possible to offer greater reward this year to those students who present the best papers. For the best papers submitted prizes will be awarded as follows:

The first three winners will receive expense money, up to a total of $150, for the group of three to enable them to attend the Inter-

national Grain and Hay Show in Chicago. The amounts granted will vary with the distance the winners are from Chicago. For example, if a California student won first and an Illinois student second, it would be desirable to grant the California student a greater proportion of the money as his expenses would be greater. The student must make the trip in order to receive the award. The committee reserves the right to adjust this as conditions warrant. In addition, the three high men shall receive a year's subscription to the JOURNAL of the American Society of Agronomy.

The $25 originally offered by the American Society of Agronomy will be added to the Board of Trade fund to award additional prizes of $25, $20, $15, $10, and $5 for 4th, 5th, 6th, 7th, and 8th place winners, respectively.

Essays must be prepared by undergraduate students. Students graduating prior to the deadline, October 1, may submit essays providing the papers are presented prior to graduation. A certification of eligibility to qualify as an undergraduate must accompany each paper. This certification should come from the Registrar or the Dean of the college.

Papers should be typed double spaced and should not be over 4,000 words in length. *Abstracts of not more than 500 words must accompany each paper.* It is hoped that abstracts of the first three essays may be published in the JOURNAL.

Any one of the following topics may be used:

1. Pasture Improvement in the United States.
2. Controlling Noxious Weeds.
3. Breeding for Disease Resistance as a Basis for Improving Farm Crops.
4. The Importance of Soil Conservation.
5. Soil Water in Plant Growth.
6. The Rôle of Some Nutrient in Crop Production.

Papers must be in the hands of the Chairman of the committee, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than October 1, 1937.

SUMMER MEETING OF A. A. A. S.

THE American Association for the Advancement of Science summer meeting at Denver, Colorado, June 21 to 26, 1937, will include a program of Section O, dealing with the scientific background of agricultural development in the Rocky Mountain region.

Papers given by specialists within their respective fields will discuss geologic and edaphic aspects, water supply, range, horticultural, and agronomic resources. There will also be an agricultural tour, with visits at the Colorado Agricultural Experiment Station, the Horticultural Field Station, and the Dry Land Experiment Station at Cheyenne and Archer, Wyoming, and the Agricultural Experiment Station at Laramie, Wyoming. Members of the staffs of these institutions are cooperating in these arrangements, under the leadership of the Department of Agronomy, Colorado State College.

The Ecological Society of America will present a symposium on "The Scientific Control of Drifting Soils" at the above meeting.

THE SEVENTH INTERNATIONAL GENETIC CONGRESS

WE are indebted to Mr. J. W. Pincus, Consulting Agriculturist of Southbridge, Mass., for the following statement regarding the plans for the Seventh International Genetic Congress. In this connection, too, the reported arrest of Prof. N. I. Vavilov has been declared false and has been denied by Professor Vavilov himself.

With regard to the Genetic Congress, it is stated that the Congress has not been cancelled but has been postponed until 1938, providing the postponement proves acceptable to the International Committee It is expected that the genetic institutes at Moscow, Saratov, and Odessa will be completed by 1938.

SUMMER MEETING OF SOUTHERN SECTION OF SOCIETY

THE summer meeting of the Southern Section of the Society will be held in Tennessee, August 16 to 21, under the auspices of the University of Tennessee. Special conferences will be held at the three largest experiment stations, Knoxville, Columbia, and Jackson.

An automobile tour has been arranged through the heart of the Tennessee Valley with visits to several of the large dams and to Muscle Shoals. An opportunity will be afforded of studying at first hand the soil conservation program of the Tennessee Valley Authority. Agronomists outside the southern area are especially invited to participate.

NEWS ITEMS

V. L. WEISER, Assistant Research Agronomist of the Vermont Agricultural Experiment Station, has resigned to accept a position with the Soil Conservation Service, Chatham, Virginia. David E. Dun' lee, graduate of Connecticut State College, will succeed Mr. Weiser this June after receiving his master's degree from the Vermont Agricultural College.

THE NATIONAL FERTILIZER ASSOCIATION has prepared in mimeograph form the Proceedings of the Twelfth Annual Meeting of the National Joint Committee on Fertilizer Application which was held at Washington, D. C., November 17, 1936. A limited number of extra copies of the Proceedings is available to interested persons as long as the supply lasts. Requests should be addressed to H. R. Smalley, National Fertilizer Association, 616 Investment Building, Washington, D C.

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AN INVENTORY OF FORAGE SPECIES AND THEIR IMPROVEMENT FOR PASTURE IN THE NORTHEASTERN STATES[1]

HOWARD B. SPRAGUE[2]

IN making an inventory of forage species and their improvement for pastures, it is assumed that the latter portion of the topic is the more important. Merely to list the forage species would require but a moment. There are hardly more than 15 or 20 important legumes and grasses in permanent pastures of the 12 northeastern states, whereas within each species the number of forms which are of potential value because of one or more distinct characters is probably very large. At least, this has proved to be the case in other crop species whenever a careful study has been made. The tremendous importance of pastures as the cheapest and most satisfactory feed for cattle, sheep, and horses warrants a careful survey of the plant resources present in pasture species, the propagation of those strains showing superiority in those characteristics of value, and the combination in single strains of as many superior traits as may be possible.

The value of individual strains will depend on how well they serve the general objectives of pasture improvement. Among these objectives may be listed the following: (a) The production of more feed per acre at a low unit cost; (b) the comparatively uniform distribution of growth throughout the entire growing season; (c) the production of high quality feed, rich in protein and minerals; and (d) high palatability.

SOIL VERSUS PLANT IMPROVEMENT

In seeking new plants or in improving well-known species to meet these aims, it is necessary to decide whether to concentrate on a search for plant forms which are adapted to poor or depleted soils or to seek those which are superior on soils which have been well managed with adequate lime and mineral treatments. In other words, shall we attempt to improve forage species for soils as they now stand in the

[1]Contribution from the Department of Agronomy, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Journal series paper. Also presented before the joint session of the Northeastern Section of the Society and Section O of the American Association for the Advancement of Science at Atlantic City, N. J., December 29, 1936.

[2]Agronomist.

pastures of the Northeast, or shall we improve these soils with the purpose of supporting better species and strains?

Probably neither alternative quite meets the needs of the situation as well as a combination of the two. Nevertheless, one must recognize the inherent weakness of breeding strains adapted to poor soils. Species and strains which are highly efficient in the removal of soil nutrients merely hasten soil degradation. Thus, redtop which has a considerably greater capacity for obtaining calcium from the soil than Kentucky bluegrass or white clover, must of necessity exhaust the supply of this element more rapidly, unless it be maintained by suitable treatment. Depletion of calcium and other bases is a condition not to be treated lightly, since a soil once strongly depleted cannot be restored to its former high level of fertility merely by the addition of lime and minerals. More or less permanent changes in composition and structure of the soil, particularly the colloidal fraction, result when prolonged removal of bases occurs without restitution. Doubtless, it will be found advantageous to improve both plants and soils simultaneously. Certain of the poorer soils may not be brought to a high level of fertility as economically as others, and the improvement of grasses on such soils which are maintained at lower levels or are being improved gradually, will be essential. Since the most desirable species, however, are those making satisfactory growth only on reasonably fertile soil, it will be necessary for soil improvement to precede the adoption of improved plant strains on the majority of pasture lands.

DOMINANT PASTURE SPECIES

Rather comprehensive surveys of pasture vegetation in the Northeast have been made by Sprague and Reuszer (13)[3]; Cooper, Wilson, and Barron (5); Johnstone-Wallace (7, 8, 9, 10, 11); Brown (3, 4); Beaumont (2); Grau (6); and by others. It is significant that the principal species involved are nearly identical in each of these states. The most prominent legume is white clover, with very small amounts of yellow trefoil (*Medicago lupulina*) and alsike clover. Occasionally sweet clover occurs on certain soil types or along exposed cuts on roads, and the native rabbit's foot clover and hop clover appear on poor upland soils. Traces of bird's foot trefoil, red clover, and zigzag clover are also found.

Among the grasses, Kentucky bluegrass, timothy, and orchard grass, appear on stronger soils; redtop, Colonial bent, creeping bent, and Canada bluegrass on somewhat weaker soils; and the fescues on still poorer soils. Consideration might well be given also to Reed's canary grass and meadow foxtail which thrive particularly well on wet lands, and to meadow fescue for uplands. Sweet vernal grass and poverty grass occupy greatly depleted pastures; however, these species are so low in yielding ability, nutritive value, and palatability that we might well ignore them.

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[3]Figures in parenthesis refer to "Literature Cited", p. 434.

LEGUME BREEDING

It seems logical that an improvement program for pasture species should stress legumes. As a group legumes are more valuable than grasses, due to their nitrogen-fixing ability, high protein content, high mineral content, particularly calcium and phosphorus, superior palatability in all growth stages, and greater resistance to drouth.

WHITE CLOVER

The most important pasture legume is native white clover which is widely distributed but abundant only on soils well supplied with available lime, phosphates, and potash. Preliminary observations have shown great differences in appearance of plants collected in various habitats. It does not seem unreasonable to expect to find some strains which will excel because of deeper root penetration and greater resistance to drouth. Possibly other strains will show stronger growth in the cool periods of early spring and late fall, and a greater tolerance to midsummer heat. The aggressiveness of some strains is known to be greater than that of others. This may be due to development of longer petioles of leaves in dense vegetation, permitting the clover to obtain the necessary light in spite of vertical competition. Ladino clover displays this feature, but its possession of other adaptive characters has not yet been proved. The rapidity of horizontal occupation is influenced by the type of runner, with long runners having an apparent advantage over short ones. Stout fleshy runners appear to be more easily injured by the trampling of grazing stock; consequently, selection for slender and rather tough creeping stems may be advantageous.

The plant breeder hopes to find white clover strains which are more efficient in obtaining phosphates and potash from the soil. These elements are not leached from the soil, but when applied as fertilizers, they are soon converted into unavailable forms under many soil conditions. If strains of white clover may be isolated which approach sweet clover in feeding power for these soil minerals, the value of clover in pastures would be immeasurably increased. Since it has been shown that the top growth of a legume may vary greatly in its phosphorus content, it will be necessary to supplement observations on yield with chemical analyses for phosphorus and calcium to avoid the selection of types that are merely able to carry on normal life processes with less of these essential elements.

White clover has the reputation of being a temperamental species, occupying an area rather completely for a year or two and then giving way to grasses. There are several possible causes for this behavior, and we shall not know which characters to choose in a breeding program until the true cause or causes are known. Does the accumulation of soluble nitrogen eventually interfere with nodulation and thus give grass the advantage in competition? If so, perhaps strains which do not make such complete occupation of the soil will be more permanent. On the other hand, longevity may be a matter of resistance to diseases, or of ability to endure periods of extreme summer weather, or of winter heaving. Still another possible cause of clover

failure may be temporary exhaustion of available soil minerals; a condition which may readily be corrected with lime and fertilizer.

Whatever other characters may be found of value in a breeding program, attention must be given to seed habits. Preliminary observations have already shown marked differences in blooming and seed production of white clover strains. It is obvious that seed of superior strains must be produced rather readily if a supply is to become available for use in improving pastures. It may be necessary to compromise on types which are not quite so vigorous in vegetative growth in order to have adequate flowering and seeding.

OTHER LEGUMES

With regard to other legumes, certain of those factors listed for white clover should be of value with these. Alsike clover, although included in all textbooks as a perennial, is distinctly biennial in its behavior in New Jersey. Whether this be due to disease susceptibility or to other factors is not known. Possibly native types can be found in pastures which have greater longevity and that also possess strongly decumbent or prostrate stems. Seed setting will be a most important consideration with this and other non-stoloniferous species, since new plants will be established solely by this means. Alsike is naturally a deeper rooted species than white clover, and thus may be expected to continue growth for a longer period after the onset of drouth. Selection may accentuate this character and make the species of real value on upland soil types.

Much the same characteristics as those listed for alsike may be sought within medium red clover and Mammoth clover for use on pastures. Since Mammoth clover is longer-lived than medium red clover, and is also believed to be a stronger feeder for nutrients on soils of limited fertility, attention should possibly be centered on Mammoth clover to the exclusion of medium red types. The isolation or development of true pasture types with strong feeding power for soil minerals may greatly change the present situation with regard to periodic scarification of the sod and reseeding of permanent pastures.

Zigzag clover (*Trifolium medium*) is a potentially valuable legume for pastures, since it is stoloniferous by *underground* stems and likewise appears to have considerable adaptation to soils of only moderate fertility. This species has the great weakness of producing seed very sparingly because of high sterility in the flowers. Undoubtedly seed setting may be improved by breeding, following which selection may be practiced for other desirable characters.

Efforts may also be directed to the improvement of sweet clover, although this plant appears to have more merit as a temporary than as a permanent pasture species, and to certain other species which are not now generally considered valuable pasture species. Bird's foot trefoil (*Lotus corniculatus*) and small yellow trefoil (*Medicago lupulina*) are doubtless worthy of serious attention by the plant breeder. Barron's recent find of an aggressive pasture type of bird's foot trefoil in New York is sufficient proof of this belief. Crown vetch (*Coronilla varia*) shows considerable vigor on unimproved soils and might

be improved to meet pasture requirements. Its underground creeping stems and deep rooting habit are favorable characters. There are a number of wild legumes which may merit consideration. However, in view of the many difficulties involved in the domestication of wild species, it seems expedient to concentrate at this time on the improvement of species already cultivated and known to be useful on pastures rather than on a search for new species.

GRASS BREEDING

Valuable as legumes are in pastures, we must recognize the predominance of grasses under most conditions. Pasture grasses of suitable types that are properly managed are certainly desirable feed. The breeding of pasture forms in various grass species by Prof. Stapledon in Wales and Dr. Bruce Levy in New Zealand are classic examples of the progress that may be made in improving these plants. Unfortunately for us, our most valuable pasture species are not those which have been improved by these breeders.

KENTUCKY BLUEGRASS

Kentucky bluegrass is the most important pasture species of the Northeast, but it is now limited to rather fertile soils. Since this bluegrass has a wide geographic distribution, however, it is conceivable that forms may be found which have a stronger feeding power for soil minerals than those commonly produced from commercial seed. It is already a species with desirable early- and late-season growth habits, high yielding ability, reasonably good palatability and nutritive value, and strong aggressiveness. Even these characters may be improved by breeding, and certainly efforts should be made to find or develop forms with deeper root systems under average soil conditions. At present we do not know the reasons why grasses fail to penetrate as deeply on eastern soils as in certain other regions, but we may search optimistically for types with this desired character which would increase the forage-producing ability in the dry midsummer period Kentucky bluegrass is also susceptible to leaf spot and other diseases and resistance to these should be within the breeder's realm.

ORCHARD GRASS AND TIMOTHY

Both orchard grass and timothy are valuable pasture species, but neither are thoroughly at home on soils of weak fertility. The ability of orchard grass to grow in early spring and continue in late fall and its tolerance of summer heat and drouth make it a valuable species in mixed pastures. The accusation of low palatability as characteristic of orchard grass seems largely unjustified, for this is true only in spring during the period of seed stalk production. Since it is an early bloomer, attention is drawn to the unpalatability of this species more than to others. As a matter of fact, observations in New Jersey indicate that all of the pasture grasses are unpalatable to milk cows during seed stalk formation, and this unpalatable stage comes at different times during the summer due to normal differences in blooming time

for the various species. Great differences in orchard grass types are already known. There is every reason to believe that forms well adapted to our soils and climate may be found or bred, which also have the desired leafiness and basal type of growth, longevity under actual grazing, and perhaps even greater depth of root system and feeding power for soil minerals. Seed setting ability in pure cultures also will be a necessary attribute.

Timothy is such a palatable species at nearly all seasons and stages of growth and is so well suited to this climate that efforts should surely be made to produce a suitable pasture type. Dwarf leafy forms, with deep roots will permit full exploitation of timothy's ability to produce feed during the period from mid-June to the end of July. Although timothy occurs rather commonly in pastures, it seems likely that many or most of these forms have become established through recent introduction of seed in manure. However, pasture types must also be present and a satisfactory search should isolate such forms.

Little use has been made of meadow fescue for pasture, since it occupies much the same place in mixtures as timothy. It is quite conceivable, however, that this species will prove even more productive and capable of enduring continued grazing, since it naturally has somewhat greater longevity and has somewhat deeper seated crowns. Breeding for resistance to leaf rust should prove desirable since meadow fescue suffers considerably from this disease in late summer and fall. Although meadow fescue is now less common than timothy and orchard grass in eastern pastures, there may be an opportunity of collecting superior forms by a careful survey of existing populations.

BENT GRASSES

Among the grasses adapted to soils of lower fertility, redtop is undoubtedly the most important species. The wide range of adaptability to extremes of both soil and climatic conditions makes it invaluable in any pasture, particularly since pastures have so regularly been relegated to soil on which cultivated crops cannot be easily grown. Redtop makes its maximum growth somewhat later in the season than timothy and meadow fescue, and thus produces herbage when it is most needed to maintain uniform feed production in midsummer. Possibly redtop's greatest weaknesses are its inferior palatability, and its lack of leafiness under close grazing. Its strong feeding power for soil minerals may be fully exploited in case these other defects can be remedied by the plant breeder. Redtop is also lacking in aggressiveness, which might be remedied by selection. The great variability which characterizes this species should make it a favorable subject for improvement.

Colonial bent resembles redtop in feeding power for minerals, as well as in the period of maximum growth, but is superior in palatability. However, it is largely non-stoloniferous and lacks aggressiveness. Also, it is susceptible to several disorders, particularly the brown patch diseases under heavy nitrogen fertilization or abundant moisture. Correction of these weaknesses would greatly improve the pasture value of the species. Lack of heat tolerance is a serious defect com-

monly found with sod produced from commercial seed. However, a careful search of native pasture forms might disclose strains with a wider temperature range.

Creeping bent grass has much the same palatability as colonial bent, but it is largely confined to moist soils in this region. Since many pastures contain imperfectly drained areas, the improvement of species specially adapted to such conditions may prove worthwhile. Creeping bent is strongly stoloniferous with surface stolons, and this character may be either a valuable or harmful one. Some strains produce runners with long internodes which do not make adequate contact with the soil for rooting at the nodes. Others produce so dense a mat of stolons that all other vegetation is crowded out, and eventually the mat becomes so thick that adequate rooting of the stems fails. Doubtless suitable types may be found which will root sufficiently well to maintain the species without excluding other plants. A combination of this character with a high degree of leafiness and yielding ability should be possible. Breeding for resistance to the same diseases as those attacking colonial bent will be important with creeping bent.

CANADA BLUEGRASS

Canada bluegrass is nearly as important as redtop on Northeastern pastures because of its wide tolerance of unfavorable soils. It is the predominant grass on many drouthy upland soils of poor fertility and also on heavy clay soils with imperfect drainage and low fertility. This grass has the great advantage of making its maximum growth in midsummer when many other species are nearly dormant. If the species were more leafy and palatable it would be useful on a very wide range of pasture soils. Undoubtedly improvement along these lines is possible. The seed habits of the species are already good and exploitation should be relatively simple.

OTHER GRASS SPECIES

Plant breeders may easily uncover superior strains of other forage species which would prove of great value on pastures. Thus, the stoloniferous, aggressive form of red fescue found in the vicinity of Lake Champlain in New York State should be a valuable strain, although it will require improvement in adaptation to permit its use in other habitats and in palatability to make it fully useful as pasturage. Reed's canary grass, which occurs naturally on many swampy pastures in the Northeast and occasionally on upland soils, may prove quite useful if more palatable forms are isolated. Little has been said of meadow foxtail, a wet-land grass with high palatability which occurs sparingly in the Northeast and is capable of much earlier spring growth than other species adapted to wet habitats. Undoubtedly many forms of these various species are present in permanent pastures which will be useful as they now exist, and other forms have features which may prove useful in developing synthetic strains.

In all grass breeding, it is highly essential that adequate attention be given to nutritive value and mineral content. Fortunately, nutritive value usually accompanies palatability, so that selection of

palatable types will automatically insure fairly satisfactory nutritive value. Mineral content, however, is not necessarily associated with either nutritive value or palatability. In species now found commonly on infertile soils, such as Reed's canary grass, the mineral content may be far below animal requirements in all stages of development, even though growth of the plant is quite satisfactory.

It is interesting to note that Maynard (12) considers the average pasture as an inadequate source of minerals for milk cows, and recommends that supplemental minerals be given during the grazing season. Surely this need not be true, particularly on pastures with mixed vegetation on well-managed soils. Although the general tendency is for grasses to fall off greatly in phosphorus content during the dry period of midsummer, the comparatively high phosphorus content of orchard grass reported by Archibald and Bennett (1) indicates that considerable improvement in mineral content is possible. Certainly a mixture of legumes and grasses should improve the mineral content of pasturage as well as the protein content. There seems to be no reason, however, for placing principal reliance on the mineral content of the legumes alone if proper attention be given to this characteristic in grasses.

SUMMARY

In conclusion, it may be appropriate and not too optimistic to state that the plant breeder has before him an exceedingly fertile field in the improvement of pasture species. Ten or 15 years ago, little interest was shown in pastures; today the situation is entirely changed. Nearly every agronomist recognizes pastures as being probably the greatest undeveloped agricultural resource of the Northeast, and livestock men are seeking information on the establishment and management of productive pastures.

We may look forward to great improvement of forage species in a relatively short time, for the plant breeder may profit greatly by the experience gained in breeding other field crops. The choice of effective breeding methods is still a debatable question, but this should prove no handicap at first. The urgent need just now is a thorough survey of each pasture species to determine the range and value of forms now growing in this region.

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EFFECT OF MATURITY ON CHEMICAL COMPOSITION OF LEGUMINOUS FORAGE PLANTS[1]

A. J. PIETERS[2]

IN considering changes which take place in the relative proportions of nutrient constituents with advancing maturity in legumes, from one standpoint the answer is not far to seek. There is a considerable literature in which analyses of alfalfa, red clover, and soybeans cut at different stages of maturity are discussed, while the data on lespedeza are much less satisfactory.

It will not be necessary to go into this literature exhaustively, but a few examples will be given to bring the facts under review. The agricultural experiment stations of Colorado, Kansas, Nebraska, Ohio, and elsewhere have published on the effect of advancing maturity on the chemical composition of alfalfa. In these studies alfalfa was cut at different stages, measured in terms of bloom, as pre-bloom, early bloom, 1/10th in bloom, etc. Selected examples are given in Tables 1, 2, and 3.

TABLE 1.—*Changes in the composition of alfalfa under Colorado conditions.**

Stage of development	Cutting	Ash	Crude fiber	N-free extract	Crude protein	Ether extract
Early bud	1st	10.24	26.0	36.20	20.33	1.87
Early bloom	1st	9.52	29.18	35.74	18.22	1.99
Late bloom	1st	8.29	31.97	35.97	16.66	1.86
Early bud	2nd	9.43	26.10	31.73	25.41	2.16
Early bloom	2nd	7.54	35.43	32.12	18.06	1.92
Late bloom	2nd	7.23	40.36	29.88	14.82	1.54
Early bud	3rd	9.69	28.29	30.91	22.52	2.36
Early bloom	3rd	8.43	32.84	34.21	17.45	1.61

*DOUGLAS, EARL, TOBISKA, J. W., and VAIL, C. E. Studies on changes in vitamin content of Alfalfa hay. Colo Agr. Exp. Sta. Tech Bul. 4. 1933.

TABLE 2.—*Changes in the composition of alfalfa under Nebraska conditions.**

Stage of development	Ash	Crude fiber	N-free extract	Crude protein	Ether extract
Pre-bloom	11.24	25.13	38.72	21.98	2.93
Initial bloom	10.52	25.75	40.67	20.03	3.03
1/10th bloom	10.27	27.09	40.38	19.24	3.02
½ bloom	10.69	28.12	39.45	18.84	2.90
Full bloom	9.36	30.82	38.70	18.13	2.99
Seed stage	7.33	36.61	39.61	14.06	2.39

*KIESSELBACH, T. A., and ANDERSON, ARTHUR. Alfalfa investigations. Nebr Agr. Exp. Sta. Res. Bul. 37. 1926.

[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Also presented before the joint session of the Northeastern Section of the Society and Section O of the American Association for the Advancement of Science at Atlantic City, N. J., December 29, 1936.

[2]Principal Agronomist.

TABLE 3.—*Changes in composition of alfalfa under Kansas conditions.**

Stage of development	Ash	Crude fiber	N-free extract	Crude protein	Ether extract
Bud stage	8.65	23.35	38.92	18.37	1.82
1/10th bloom	8.35	24.09	38.92	17.85	1.77
Full bloom	7.99	25.80	38.90	16.21	1.79
Seed stage	6.95	30.49	37.28	14.08	1.73

*SALMON, S. C., SWANSON, C. O., and MCCAMPBELL, C. W. Experiments relating to time of cutting alfalfa. Kans. Agr. Exp. Sta. Tech. Bul. 15 1925.

These analyses agree substantially in showing that with advancing maturity the percentage of protein tends to decline and that of crude fiber to increase, while the fat and nitrogen-free extract do not change materially.

The figures given in Morrison's *Feeds and Feeding* (Ed. 20, 1936), may be given as summarizing all available data on this subject (Table 4).

TABLE 4.—*Average composition of alfalfa, red clover, soybeans, and lespedeza at different stages of maturity.*

Stage of development	Digestible proteins	Total digestible nutrients	Average total composition					
			Protein	Fat	Fiber	N-free extract	Mineral matter	Number of analyses
			Alfalfa					
Before bloom	14.2	53.2	19.0	2.7	22.3	36.6	9.8	12
1/10 to 1/2 bloom	11.0	50.1	14.9	1.7	30.1	35.0	8.9	29
3/4 to full bloom	9.9	49.7	14.0	2.0	30.3	35.8	8.3	21
Past bloom	8.6	44.9	12.8	2.1	31.9	36.1	7.5	10
			Red Clover					
Before bloom	12.0	56.4	18.7	3.6	18.3	41.8	7.2	2
In bloom	7.8	53.4	12.6	3.6	26.2	39.6	6.2	45
Past full bloom	7.3	51.7	12.3	3.6	28.1	36.8	7.4	9
			Soybeans					
In bloom or before	13.1	51.0	17.4	3.4	21.4	39.3	10.0	8
Seed developing	11.2	50.0	14.9	2.4	28.2	38.0	7.4	22
Seed well developed	11.9	53.0	15.8	5.1	27.2	36.6	6.1	16
Seed nearly ripe	11.8	56.0	15.7	6.8	24.8	39.3	4.1	2
			Annual Lespedeza					
Before bloom	10.7	55.5	14.2	2.6	20.8	45.2	6.2	3
In bloom	10.1	53.1	13.4	1.8	25.8	42.8	5.2	6
After bloom	8.9	51.1	12.5	1.6	31.3	39.1	4.5	6

For red clover the story is the same. Atwater in Connecticut, Jordan in Pennsylvania, Hunt in Illinois, and Snyder in Minnesota, to

mention only a few workers, have shown that the change in percentage of feed constituents with advancing maturity is of the same order as that in alfalfa.

Again, Morrison has averaged all American analyses, bringing out the fact that protein declines, fiber increases, while fat and nitrogen-free extract change but little.

In soybeans the situation is complicated by the formation of the seeds. While protein and fat content decline at first, there is an upward tendency as the seeds develop. The changes in this crop have been most carefully studied by Borst and Thatcher (Ohio Agr. Exp. Sta. Bul. 494, 1931). The picture as presented by Morrison of the averages of all analyses brings out the fact that after the first drop in protein, fat, and total digestible nutrients, there is a marked increase as the seeds develop.

In the annual lespedezas the percentage of all food constituents appears to decline with advancing maturity, but the general picture resembles that for alfalfa and red clover.

Lespedeza sericea is too new a crop for workers to have done a great deal with, but a series of analyses made by the U. S. Dept. of Agriculture shows that so far as protein is concerned there is a marked decline in percentage with advancing maturity while at the same time there is an increase in the undesirable tannin (Table 5).

TABLE 5.—*Percentage of protein and tannin in Lespedeza sericea cut at weekly intervals at Arlington Farm, Va., May 29 to July 31, 1935.**

Date cut	Crude protein in whole hay	Tannin in whole hay
May 29	17.95	5.1
June 6	15.54	7.7
June 12	14.66	6.86
June 20	14.41	9.0
June 26	12.85	8.2
July 3	12.32	8.0
July 10	11.29	7.88
July 17	10.55	8.68
July 24	10.7	9.14
July 31	9.93	8.0

*Calculated from analyses of protein content by W. L. Hall, Bureau of Agricultural Economics, and of tannin by Ralph Frey, Bureau of Chemistry and Soils.

Not only does the percentage of the important nutrients change with advancing maturity, but the digestibility of these nutrients also changes for the worse, though the digestibility of the protein appears to suffer more than that of the fat or nitrogen-free extract.

Woodman, Evans, and Norman in England studied the digestibility of alfalfa in connection with an exhaustive study of the changes in chemical composition occurring with advancing maturity. Digestion experiments were carried out with alfalfa hay cut in bud stage, June 7 to 17, and in the flower stage, July 2 to 11, with the result shown in Table 6.

The work of Salmon, Swanson, and McCampbell in Kansas led to substantially the same conclusion, that the digestibility of the various

TABLE 6.—*Digestibility of alfalfa hay cut at different stages of development.*

	Cut in bud stage, June 7–17	Cut in flower stage, July 2–11
On the basis of dry matter:		
Digestible crude protein	15.49	12.96
Digestible ether extract	0.66	0.20
Digestible nitrogen-free extract	31.33	27.62
Digestible fibre	11.08	12.66
Total digestible organic matter	58.56	53.44
Starch equivalent	50.81	42.44

nutrients declines with increasing maturity of the plant. In soybeans, on the contrary, owing to seed formation, the percentage of total digestible nutrients increases with maturity.

The mineral content also changes, and lime and phosphorus content is of importance in considering the feeding value of leguminous hay. In general, it has been found that the phosphorus content decreases and the calcium content increases or changes little with advancing maturity. Unfortunately, we do not know what the weather was when the material analyzed was collected. Daniel and Harper in Oklahoma have shown that in prairie hay and in alfalfa hay both calcium and phosphorus content may be influenced by soil moisture. They say, "During periods when the rainfall was high the calcium content of the plants decreased and the phosphorus content increased. . . When the effective rainfall was low the calcium content of the plants increased and the phosphorous content decreased." The record of the mineral content is therefore open to some uncertainty.

Vitamins, too, which are now recognized as an important constituent of feeding stuffs, have been found to be rather more abundant in young than in older plants. Douglas, Tobiska, and Vail concluded that, "hay cut at the early bloom stage contains more vitamin A as a rule than that cut at other stages of growth, the methods of curing being the same." They state further that there was "a small diminution of vitamin B with increasing age of the plant," but that there was slightly more vitamin G in the early bloom than in the early bud stage.

Another factor to be considered is yield. The number of pounds of dry matter times the percentage of nutrients equals the total nutrients secured per acre. Naturally the yield of a crop cut very young will not be as great as that from the same field cut at a somewhat later stage. What will be the total quantity of digestible nutrients harvested per acre? The farmer who feeds his own forage will be interested in that; the one who buys his feed in the quantity of digestible nutrients per ton, and the two may be quite different.

Kiesselbach and Anderson found that while the yields of alfalfa were higher the more mature the cutting, this increase was not proportional to the decline in percentage of protein so that actually more protein per acre was secured from the pre-bloom cutting than from the later cuttings. This was not true of the fat and nitrogen-free extract which increased in the next two cuttings.

In some studies on *Lespedeza sericea* made at Arlington Farm it was found that, while the percentage of protein declined with age, the yield from the later cutting was so much greater that the total amount of protein per acre was larger in material cut June 11 than in that cut June 4. The digestibility was probably lower, however, and in that case the extra yield would not be profitable.

Salmon, Swanson, and McCampbell found that the total quantities of crude protein, fat, and nitrogen-free extract were greater in the material harvested in the 1/10th bloom and full bloom stages than in the bud stage, but the feeding results do not bear out the conclusion one might draw to the effect that that cut at the later stages was more valuable. The alfalfa harvested was fed to yearling steers and to 2- and 3-year-old steers, and in every case it took less of the hay cut at bud stage to make 100 pounds of gain than of that cut at the later stages. When their figures are calculated to the pounds of gain per acre that were made, it again appears that the alfalfa cut in the bud stage made more pounds of gain per acre than that fed at later stages.

Possibly the digestibility of the nutrients may have had an influence here or the fact that the early cut hay contained more vitamins A and B. If the farmer fed this hay, therefore, he made a greater profit out of the hay cut at the earlier stages; if he sold it he made less, unless he got a premium.

But in the case of alfalfa, and probably of *Lespedeza sericea*, there is still another consideration, *viz.*, the effect of this early cutting on the stand. It is well known that too early and too frequent cutting have a bad effect on the stand of alfalfa The profitableness of the practice will depend therefore not only on the immediate results but on future expenses and profits.

SUMMARY

In this brief review of the problem, it has been shown that the valuable food constituents are present not only in greater proportion in the earlier stages of legumes, but that they are more digestible. The fact that at a later stage the natural increase in organic matter will carry with it a greater production of nutrients per acre does not necessarily mean that these larger amounts will have a greater feeding value.

From the farmer's standpoint the important consideration is net returns per acre, taking due account not only of returns in any one year but for a term of years. The result may vary depending on whether he feeds his own produce or sells it at the market price per ton.

THE INFLUENCE OF GRAZING MANAGEMENT AND PLANT ASSOCIATIONS ON THE CHEMICAL COMPOSITION OF PASTURE PLANTS[1]

D. B. JOHNSTONE-WALLACE[2]

GOOD pasture management means a system of fertilization and grazing which insures that an animal is able to consume, during each day of the grazing season, the maximum amount of feed of a chemical composition suitable for the maintenance of health and condition and for the production of milk, meat, bone, wool, or other product desired.

The technic of grazing management can best be studied by careful observation of the habits of grazing animals (Fig. 1).

Under the conditions prevailing in the northeastern states cattle show a preference for pasturage consisting of short leafy herbage. They may graze such herbage to within half an inch of the surface of the ground, and continue steadily without raising their heads for periods of more than 30 minutes, the head moving from side to side as the cow slowly moves forward. There is a limit to the length of the herbage which can be consumed rapidly and easily in this way and a dense sward with a height of about 4 inches appears to approach the ideal (Fig. 2). The senses of sight, taste, and smell appear to be used in determining the herbage to be eaten. The leaf is preferred to the stem. Short young herbage low in fibre is eaten in preference to old, tall, stemmy, and highly fibrous herbage. Certain grasses, legumes, and weeds are eaten in preference to others Herbage growing in the vicinity of cattle droppings is avoided even when luxuriant in appearance, and this appears to be associated with the odor from the droppings rather than with the flavor of the herbage. A grazing animal not only removes herbage when grazing but also treads heavily on the turf. This treading action of stock influences sward formation considerably.

The grazing habits of animals determine the type of pasture required. The most desirable pasture is one which permits a grazing animal to consume the maximum amount of feed each day during the grazing season.

Observations by Woodward (17)[3] and other investigators indicate that a good cow in a good pasture can consume about 150 pounds of green herbage containing about 30 pounds of dry matter in a day. Cattle do not graze continuously during a 24-hour period, however, the actual period of grazing is confined to about one third of the day, the remaining two thirds being spent in resting and chewing the cud (14). Naturally the time spent in grazing, resting, and chewing will vary with the kind of grazing animal, the type of pasture,

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[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Also presented before a joint session of the Northeastern Section of the Society and Section O of the American Association for the advancement of Science at Atlantic City, N. J., December 29, 1936.

[2]Professor.

[3]Figures in parenthesis refer to "Literature Cited", p. 454.

FIG. 1.—The technic of grazing management can best be studied by careful observation of the habits of grazing animals.

and the climatic conditions. A cow must have favorable grazing conditions provided in order to consume 150 pounds of green herbage in 8 hours with a mowing apparatus only about 3 inches in width. On many pastures because of low fertility, unfavorable weather conditions, or bad grazing management, the task becomes impossible (6). At Cornell University the productivity of the pastures since 1932 has varied from 360 pounds of dry matter per acre on an unimproved pasture in a very dry season up to 6,300 pounds of dry matter per acre on a good wild white clover pasture in a favorable season. Daily fluctuations in the rate of growth are also of importance and they have varied in one season from 7 pounds up to 95 pounds of dry matter per acre per day in the same pasture (8).

Ellenberger, *et al* (2), in Vermont, reported annual pasture yields varying from 261 pounds up to 4,031 pounds of dry matter per acre.

The chemical composition of the herbage present in a pasture is not a reliable indication of the composition of the herbage consumed. In 1928, in Essex, England, the author picked herbage by hand from a strip adjoining that which was being grazed by a cow. The herbage collected corresponded as closely as possible with that which the cow selected. The dry matter of this herbage was found to contain 29% of protein (7).

Ellenberger, *et al.* (2) reported an average protein content of 19% in plucked samples from 21 Vermont pastures. Orr (12) records that the herbage eaten by stock on a Romney March pasture in England contained 21% protein, 0.9% lime, and 0.9% phosphoric acid, whereas the herbage not grazed contained 11% protein, 0.7% lime, and 0.6% phosphoric acid.

Delayed grazing in the spring enables much of the herbage to reach a highly fibrous stage before the stock can graze it. This frequently results in part of a pasture being overgrazed while most of it is undergrazed or not grazed at all. As most of the herbage consumed is taken from the closely grazed portion, the chemical composition of the herbage present in the pasture as a whole is of little significance.

Table 1 shows the chemical and botanical composition of 30 pas-

tures in New York State on various soil types. The pastures marked P are known to have been treated previously with superphosphate. It will be observed that the protein, lime, and phosphoric acid content of these pastures is greater than from untreated pastures on the same soil types and that the proportion of clover to grass is also greater.

The pastures marked X were used to supply soil for the fertilizer experiments shown in Table 2. It will be observed that the eight soil types used all showed a marked response to phosphorus; that those with a pH below 5.5 showed a response to lime, and that one soil responded markedly to potash.

FIG. 2.—A dense sward with a height of about 4 inches appears to approach the ideal.

The changes in the chemical composition of herbage following fertilizer treatment are partly associated with the changes in the botanical composition of the herbage. Godden at the Rowett Research Institute in Scotland records (12) the following changes in the chemical composition of the dry matter of pasture herbage:

Treatment	Protein %	P_2O_5 %	CaO %
Untreated	9.15	0.29	0.59
Superphosphate	9.31	0.71	0.94
Superphosphate and lime	10.72	0.73	0.98
Lime	9.63	0.30	0.77

Vinal and Wilkins (15) at Beltsville, Maryland, record the effect of fertilizer treatment upon pure stands of Kentucky bluegrass and white clover as follows:

Treatment	Kentucky bluegrass			White clover		
	Protein %	P_2O_5 %	CaO %	Protein %	P_2O_5 %	CaO %
Superphosphate	17.37	1.12	0.78	29.98	1.26	1.97
Untreated	16.69	0.89	0.67	29.21	1.03	1.76

TABLE 1.—*Composition of dry matter of pasture herbage in New York State, Cornell University, 1932–34*

Pasture*	Soil†	pH	Pasture type	Protein %	P_2O_5 %	CaO %	K_2O %	MgO %	Botanical analysis: Grass %	Botanical analysis: Clover %
H2P	HL	7.0	Ky. bluegrass	21.47	1.01	1.15	3.90	0.53	50	20
H3	HL	—	R. I. bent	12.65	0.44	1.47	2.73	0.57	63	2
H6X	HL	6.6	Poverty	5.69	0.26	1.00	0.84	0.18	64	1
H10P	HL	—	Ky. bluegrass	14.50	0.51	1.29	2.11	0.35	80	5
H11	HL	—	Poverty	3.78	0.19	0.32	0.22	0.09	77	0
H15	OL	6.3	Redtop	14.40	0.55	0.93	3.72	0.43	76	3
H17X	OL	6.4	Poverty	4.64	0.21	0.46	0.38	0.14	80	0
H23	MS	7.6	Ky. bluegrass	23.68	0.96	1.82	3.23	0.59	50	40
H30X	MS	6.4	Canada bluegrass	5.83	0.31	0.95	0.92	0.19	70	3
H37	MS	—	R. I. bent	14.52	0.55	1.00	1.91	0.28	81	2
H40	MY	—	Poverty	7.18	0.26	0.42	1.34	0.14	80	0
H42	ML	5.3	R. I. bent	8.89	0.37	0.90	1.25	0.27	85	0
H49	FL	—	R. I. bent	6.79	0.38	1.07	1.93	0.32	70	0
H59	Cg	6.5	Ky. bluegrass	10.57	0.45	1.13	2.16	0.34	60	20
H60	Cg	4.9	Timothy	6.20	0.31	0.46	1.32	0.21	80	5
H66X	CS	4.9	R. I. bent	7.24	0.35	0.61	1.02	0.18	65	5
H73X	Hy	5.4	Poverty	4.18	0.26	0.25	0.21	0.09	80	0
H83	GF	—	Poverty	8.88	0.35	0.74	0.84	0.28	70	0
H88	MR	—	Poverty	9.84	0.25	0.16	1.29	0.12	40	0
H89	MF	5.1	R. I. bent	12.26	0.32	0.40	1.32	0.19	80	1
L50	MC	—	Poverty	9.23	0.29	0.59	1.39	0.29	64	2
L47	DL	—	Ky. bluegrass	14.80	0.75	0.88	1.93	0.50	84	10
L32	HF	—	Poverty	7.35	0.28	0.29	1.25	0.14	90	0
L30	Hy	—	R. I. bent	11.30	0.44	0.47	1.22	0.22	60	0
L16	M	—	Canada bluegrass	10.19	0.43	1.26	2.10	0.52	60	2
L13P	M	—	Ky. bluegrass	18.55	0.81	1.50	2.27	0.61	44	40
L14	M	—	R. I. bent	10.25	0.35	1.31	2.14	0.51	60	2
L34	RL	—	Poverty	12.25	0.45	0.56	1.59	0.35	40	0
G21	My	—	Canada bluegrass	6.20	0.24	0.74	0.74	0.19	80	0
G22P	My	—	Canada bluegrass	15.33	0.56	1.73	1.86	0.42	70	16
Average				10.62	0.43	0.86	1.64	0.30	68.4	6.3

*P, Received superphosphate; X, Soil used in pot experiments; H, Herkimer County; L, St. Lawrence County; G, Genesee County.

†HL, Honeoye loam; OL, Ontario loam; MS, Mohawk silt loam, MY, Mohawk silty clay loam; ML, Mohawk loam; FL, Farmington silt loam; Cg, Chenango gravelly loam; CS, Canfield silt loam; Hy, Hinckley sand; GF, Gloucester fine sandy loam; MR, Merrimac coarse sandy loam; M, Madrid loam, RL, Rubicon loamy fine sand; MC, Merrimac cobbly loam; HF, Hermon fine sandy loam; DL, Dunkirk silt loam; MF, Merrimac fine sandy loam.

TABLE 2.—*The results of pot experiments with New York pasture soils using cultivated white mustard and a mixture of grass and wild white clover as indicator crops, Cornell University, 1932–34.*

		Cultivated white mustard				
	Soil type*	O.L.	H.L.	M.S.L	C.S.L.	H.F.S.
	pH of soil	6.41	6.62	6.35	4.89	5.38
Plat 1	Untreated	4	8	4	3	3
Plat 2	Complete, Ca N P.K †	100	100	100	100	100
Plat 3	No potash, Ca N.P.	99	94	98	95	26
Plat 4	No phosphorus, Ca.N.K	5	8	10	3	20
Plat 5	No nitrogen, Ca P.K.	10	13	6	8	9
Plat 6	No lime, N.P.K.	103	98	98	77	13
Plat 7	Phosphorus	----	——	5	----	——

		Grass and wild white clover		
	Soil type*	W.S L.	L.S L	LG.S.L.
	pH of soil	5.15	4.77	5.50
Plat 1	Untreated	6	3	1
Plat 2	Complete, Ca N P K †.	100	100	100
Plat 3	No potash, Ca.N P .	87	87	92
Plat 4	No phosphorus, Ca N.K. . .	5	8	2
Plat 5	No nitrogen, Ca.P.K . . .	79	71	78
Plat 6	No lime, N.P K .	75	81	73
Plat 7	Phosphorus	83	42	73

*O L , Ontario loam; H L , Honeoye loam, M S L , Mohawk silt loam, C S L , Canfield silt loam, H F S , Hinckley fine sand, W S L , Walton silt loam; L S L , Lackawanna silt loam, LG S.L , Langford silt loam

†Ca, 2,000 lbs limestone, N, 200 lbs. sulfate of ammonia; P, 800 lbs 16% superphosphate, K, 200 lbs muriate of potash per acre.

The influence of the kind of grass and the association of wild white clover on the chemical composition of pasture herbage at Cornell University is indicated in Table 3.

Different species and varieties of grasses appear to differ in their chemical composition when grown at the same level of fertility and when harvested at approximately the same stage of maturity.

When closely grazed the variations in the protein and phosphoric acid content appear to be small, but there is considerable variation in the lime content. It is noteworthy that Kentucky bluegrass, which is so frequently associated with limestone soils, is abnormally low in lime, whereas Rhode Island bent, so frequently associated with acid soils, is abnormally high in lime.

The variation in the chemical composition of the same grass grown alone and in association with wild white clover throughout the grazing season may be greater than the variation between different grasses in the season as a whole. This is indicated in Table 4.

The wide seasonal variation in the lime content is remarkable and is an indication that the results of analyses of samples of herbage taken from different pastures at different times during the grazing season should be interpreted with caution. The variation in the pro-

TABLE 3.—*The chemical composition of closely grazed grass and the influence of wild white clover on the yield and chemical composition of pasture herbage, Cornell University, 1933.**

Grass	Yield and composition of grass grown alone				Yield and composition of grass and wild white clover (*Trifolium repens* var.) grown together			
	Dry matter lbs. per acre	Protein %	P_2O_5 %	CaO %	Dry matter lbs. per acre	Protein %	P_2O_5 %	CaO %
Kentucky bluegrass (*Poa pratensis*)	1,676	23.4	1.35	0.32	3,642	30.7	1.19	0.52
Canada bluegrass (*Poa compressa*)	2,154	27.1	1.48	1.19	3,841	31.2	1.33	1.39
Rhode Island bent (*Agrostis tenuis*)	2,065	25.3	1.21	1.36	3,709	32.1	1.27	1.36
Red top (*Agrostis stolonifera*)	1,890	23.6	1.30	1.10	3,558	31.5	1.25	1.36
Commercial timothy (*Phleum pratense*)	2,853	24.0	1.38	0.79	3,812	30.1	1.19	0.96
Aberystwyth pasture timothy No. S. 50 (*Phleum pratense* var.)	1,828	24.5	1.26	0.56	4,084	31.6	1.20	0.94
Orchard grass (*Dactylis glomerata*)	2,513	23.5	1.54	0.78	3,825	29.3	1.30	0.88
Perennial ryegrass (*Lolium perenne*)	1,678	22.8	1.36	0.78	3,360	30.2	1.19	1.08

*The plats were cut at intervals through the season when the herbage reached a height of about 4 inches. All plats were treated with lime, superphosphate, and muriate of potash. The soil was Dunkirk silt loam. The grasses were seeded at the rate of 24 pounds per acre and the wild white clover at 2 pounds per acre in May 1932.

tein content throughout the season is small if the grazing management is good. The influence of wild white clover in narrowing the ratio between phosphoric acid and lime is significant.

The experimental results shown in Table 5 indicate the influence of wild white clover on the protein content of the grass grown in association with it as well as upon the yield of herbage. It will be seen that the addition of wild white clover to a seeding of Kentucky bluegrass has increased the yield of herbage more than 500%. It will be seen also that the protein content of Kentucky bluegrass grown alone averaged 18%, whereas the same grass grown in association with wild white clover averaged 25%. This is believed to be due in part only to the nitrogen supplied by the clover. The more favorable conditions provided for the growth of the grass by the lower soil temperatures and the greater absorbtion of rainfall as a result of the type of sward produced are also believed to influence the composition.

The beneficial influence of grass on clover during the early part of the grazing season is indicated by the greater yield of clover on May 13 and 23 and June 5 when grown with grass than when grown alone. Observations indicate that this is largely associated with the protection against winter heaving given to the clover by the grass.

TABLE 4.—*Seasonal variations in the chemical composition of Aberystwyth pasture timothy No. S. 50 when grown alone and of the herbage produced by a mixture of the same grass and wild white clover grown together, Cornell University, 1933.**

Time of sampling	76A pasture timothy and wild white clover			76B pasture timothy alone		
	P_2O_5 %	CaO %	Protein %	P_2O_5 %	CaO %	Protein %
May 7	0.90	1.46	28.9	0.94	1.31	24.2
May 17	0.99	1.27	32.6	1 04	0 82	25.5
May 26	1.06	0.99	32.1	1.12	0 58	25.8
June 1	1.13	0.91	32 8	1.19	0.66	26.6
June 9	1.30	0.96	31 7	1.37	0.61	24 7
June 16	1.26	0.85	29.0	1.33	1.06	24 1
July 3	1.21	1.13	28.5	1.28	0.58	20.9
July 17	1.37	0.94	30 1	1.43	0 56	17.3
July 31	1.58	0.83	31.6	1.66	0 25	19 9
Aug. 14	1.43	0.77	33.8	1.50	0.19	22.9
Aug. 28	1.18	0 73	33.4	1.24	0.53	26 1
Sept. 7	1.09	0.88	32.3	1.13	0.47	26.6
Sept. 18	1.19	0.82	32.6	1.24	0 22	27.8
Sept. 28	1.23	0.81	32 8	1.29	0.22	28 4
Oct. 15	1.03	0 72	32 1	1 08	0 31	27.3
Average	1 20	0.94	31.6	1.26	0 56	24.5

*The herbage was cut closely when it reached a height of about 4 inches. The soil was treated previously with adequate amounts of phosphorus, potash, and lime.

The influence of wild white clover on the seasonal productivity of Kentucky bluegrass and upon soil temperatures will be seen in Fig. 3. Although the addition of wild white clover to a seeding of Kentucky bluegrass is found to influence the protein content of the bluegrass as well as the herbage as a whole, it will be seen from Table 6 that the application of nitrogenous fertilizers to a pasture sward containing wild white clover may result in a decrease in the percentage of protein in the herbage and a decrease or negligible increase in the yield of dry matter. This is associated with the decrease in the percentage of clover resulting from the application of nitrogenous fertilizers. This decrease during the 1934 and 1935 grazing seasons appeared to be most marked in the case of the cyanamid and sulfate of ammonia applications. It is noteworthy that except in the case of nitrate of soda the applications of nitrogen have resulted in a decrease in the amount of nitrogen removed per acre in the herbage.

The decreased percentage of clover following the application of certain nitrogenous fertilizers does not appear to be due entirely to the suppression of the clover resulting from a more vigorous growth of grass, but rather to the toxic effect of ammonium ions on clover which has been recorded by Blackman (1) in England.

Jones (11), in England, has shown the influence of methods of grazing management on the botanical composition of pasture herbage as shown at top of page 448.

The influence of close grazing in early May in increasing the growth of wild white clover in the Cornell University pastures is believed to

Grass and clover	Original sward	Hard spring grazing	Light spring grazing
Perennial ryegrass	65	31	77
Other useful grasses	5	5	7
Weed grasses	0	1	7
Wild white clover	30	63	9

TABLE 5.—*The seasonal production and chemical composition of Kentucky bluegrass and wild white clover when grown alone and in association. Cornell University, 1935.*

Date of cut	Plat 211, Kentucky bluegrass and wild white clover						
	Lbs. dry matter per acre per day	Clover in dry matter		% protein in clover	Ky. blue in dry matter		% protein in grass
		%	Lbs.		%	Lbs.	
May 13	26	48	12	36	52	14	26
May 23	23	29	7	33	71	16	21
June 5	64	67	43	35	33	22	21
June 14	22	62	14	35	38	9	21
June 25	27	76	20	33	24	6	21
July 12	36	75	27	34	25	9	24
July 19	23	51	12	34	49	11	30
July 31	51	52	26	38	48	24	30
Aug. 12	42	51	21	38	49	21	28
Aug 26	34	40	14	36	60	20	26
Sept 11	18	47	8	34	53	10	23
Oct 7	6	25	1	30	75	5	22
Tot. D M	4,985						
Wtd. av		55		35	44		25

Date of cut	Plat 212, Ky. bluegrass alone		Plat 215, wild white clover alone	
	Lbs. dry matter per acre per day	% protein in dry matter	Lbs. dry matter per acre per day	% protein in dry matter
May 13	4	20	1	31
May 23	4	20	1	29
June 5	11	14	33	36
June 14	6	17	19	38
June 25	4	17	30	36
July 12	6	19	34	37
July 19	6	23	16	34
July 31	5	22	29	35
Aug. 12	7	21	28	37
Aug. 26	8	20	26	34
Sept. 11	4	17	20	27
Oct. 7	1	18	3	30
Tot. D. M.	881		3,072	
Wtd. av.		18		35

TABLE 6.—*The influence of nitrogenous fertilizers on the botanical and chemical composition of pasture herbage consisting of grass and wild white clover, Cornell University, 1935.**

Treatment per acre, lbs	Dry matter per acre, lbs	Protein in mixed herbage %	Clover in herbage %	Protein in clover %	Grass in herbage %	Protein in grass %	Sulfate of ammonia equivalent in dry matter per acre, lbs
Cyanamid, 200	6,210	29	41	36.2	59	26.8	1,423
Sulfate of ammonia, 218	6,341	30	42	36.3	58	27.3	1,507
Nitrate of soda, 288	6,699	31	45	36.6	55	27.3	1,617
No nitrogen	6,276	31	51	37.0	49	27.1	1,511

*The plats were seeded with the Cornell pasture mixture in May 1932. They were cut closely when the herbage reached a height of about 4 inches. The soil received adequate applications of phosphorus, potash, and lime.

be due to the reduction in the competition of the grasses with the clover at a time when the grasses normally grow more rapidly than the clover. The injury done to the grass by close grazing in early May is beneficial to the clover by reducing competition and because the clover is made to grow more vigorously the grass is benefited later in the season to a greater extent than it was injured earlier (4). It is the results of grazing management practices on the total production and its distribution which are of greatest importance. The suppression of wild white clover by grass is associated with its intolerance of shade (5). It is for this reason that close grazing is so important in wild white clover pastures. The differences in the growth curves of Kentucky bluegrass grown alone and with wild white clover, and wild white clover grown alone will be seen in Figs. 4 and 5.

The distribution of growth throughout the grazing season and the chemical composition of the herbage available for grazing can be improved by the use of special seed mixtures designed for the purpose, when sound methods of fertilization and grazing management are employed (8). The Cornell pasture mixture for 1937 has been found to give good results at Cornell University. The distribution of growth in 1935 (Fig. 6) closely approached the ideal aimed at of a daily production of 30 pounds of dry matter per acre throughout a 6 months' grazing season. The mixture is as follows:

Kentucky bluegrass (*Poa pratensis*) .... 10 lbs. per acre
Canada bluegrass (*Poa compressa*) .... 2 lbs. per acre
Rough-stalked meadow grass (*Poa trivialis*) .... 1 lb. per acre
Aberystwyth pasture timothy No. S. 50 (*Phleum pratense* Var.) .... 6 lbs. per acre
Svalof Victoria perennial ryegrass (*Lolium perenne* Var.) .... 5 lbs. per acre
Kent wild white clover (*Trifolium repens* Var.) ...... 1 lb. per acre

There is still room for improvement in this mixture and investigations are in progress to determine constituents which will give in-

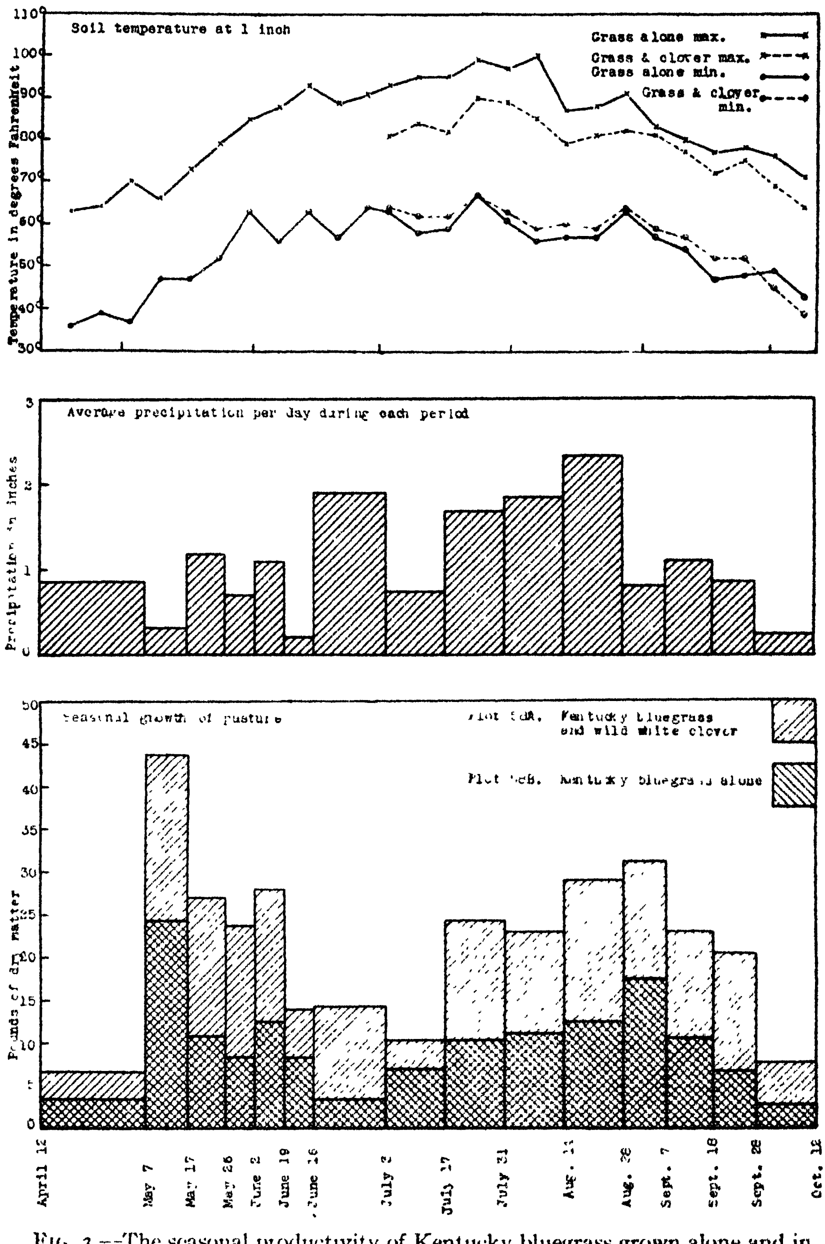

FIG. 3.—The seasonal productivity of Kentucky bluegrass grown alone and in association with wild white clover and its relation to precipitation and soil temperatures. Cornell University, 1933.

creased production during the period between the middle of June and the middle of August. At present the most satisfactory solution to this problem has been found in the utilization of meadow aftermaths

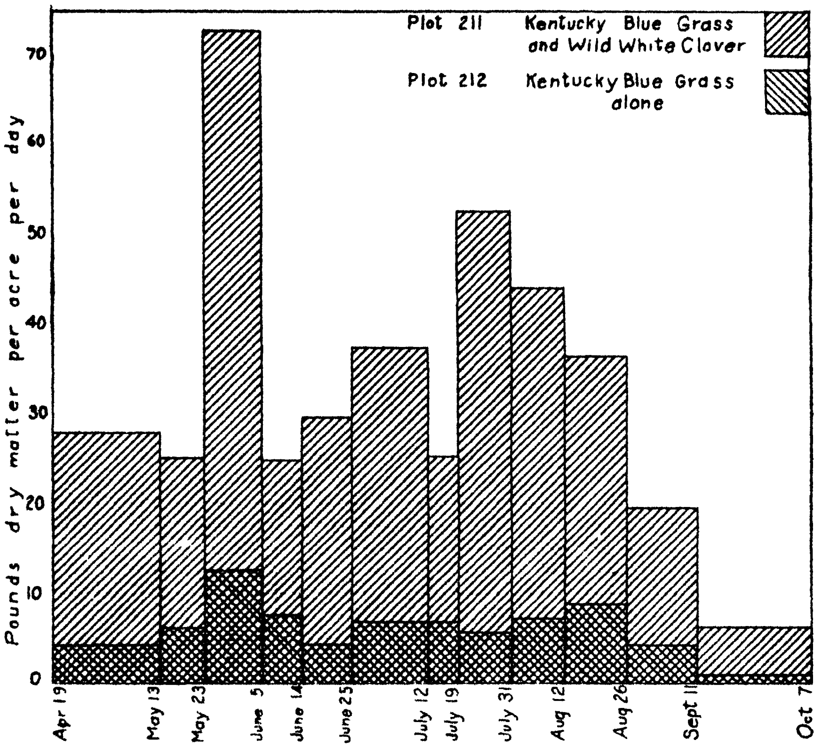

FIG. 4.—The seasonal productivity of Kentucky bluegrass grown alone and of a mixture of Kentucky bluegrass and wild white clover. Cornell University, 1935.

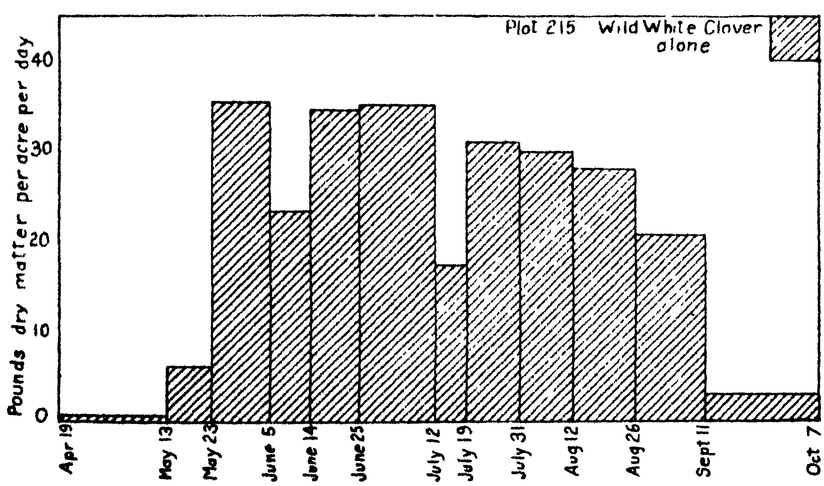

FIG. 5.—The seasonal productivity of wild white clover grown alone. Cornell University, 1935.

produced by the use of special mixtures containing wild white clover as supplementary pasture (7).

The chemical composition of the herbage consumed by grazing animals is influenced by the selective nature of their grazing. Stapledon

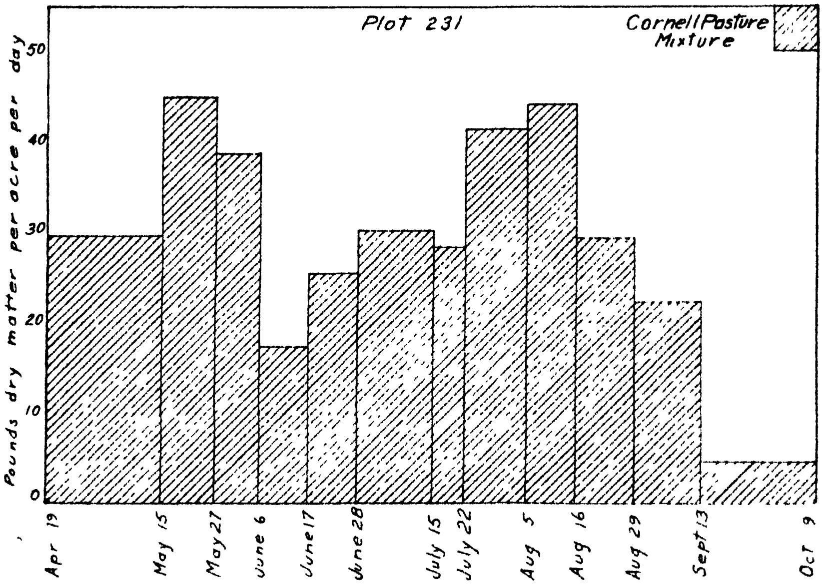

FIG. 6.—The seasonal productivity of the Cornell pasture mixture. Cornell University, 1935.

(14) at Aberystwyth has shown that leaf is preferred to stem and that certain pasture plants are eaten in preference to others, as will be seen from the following:

Herbage	Herbage present in pasture		Proportion of leaf to stem in pasture herbage	
	Before grazing %	Actual grazing %	Before grazing %	Actual grazing %
Clover	44.0	59.1	58.4	60.0
Perennial ryegrass	25.3	16.6	27.3	51.2
Other grasses	29.2	24.4	60.0	73.8
Weeds	1.3	0.0	—	—

The preference shown for leaf rather than stem influences the chemical composition of the herbage consumed. Fagan (3) at Aberystwyth found that the protein present in timothy leaves ranged between 23.8 and 27% while in timothy stems it ranged between 11.4 and 17%.

It is characteristic of true pasture types of most of the grasses that they produce a larger proportion of leaf to stem than commercial hay types.

Fertilization and good grazing management tend to discourage many pasture weeds. This is due partly to competition and partly because many weeds are consumed when mixed with more palatable herbage. Weeds such as devil's paintbrush with leaves lying close to the ground tend to grow more upright when crowded by other plants so that grazing becomes possible. Weeds are not necessarily low in feeding value and Fagan (3) at Aberystwyth reports the following analyses of certain weeds which are also found in the northeastern states:

	Protein %	Fibre %	P_2O_5 %	CaO %	K_2O %
Narrow-leaved plantain	20.25	14.84	1.07	2.25	3.37
Dandelion	19.36	17.13	0.98	1.80	4.09
Yarrow	19.90	24.30	0.91	1.08	2.81
Buttercup	16.20	16.76	0.76	1.32	2.07

The stage of maturity of the herbage when consumed influences the chemical composition as is shown by Fagan (3) with respect to orchard grass as follows:

Age when cut	Protein %	Fibre %	P_2O_5 %	CaO %
1 month	12.3	21.3	0.92	0.91
2 months	11.8	23.0	0.86	0.94
3 months	9.1	32.4	0.82	0.99

The digestibility of pasture herbage is as important as its chemical composition. Woodman (16) at Cambridge University has shown that the composition and digestibility of closely grazed pasturage compares favorably with the commonly used concentrated feeds. Samples harvested on May 11, 1925, were found to be digestible to the following extent: Crude protein, 85.4%; oil, 60%; carbohydrates, 87.4%; and fibre, 79.2%.

The fibre of closely grazed pasture herbage is almost as digestible as the carbohydrates because it is present in the form of a simple cellulose unmixed with the indigestible lignocellulose characteristic of more mature herbage. The digestibility of the closely grazed pasture herbage as a whole was found to be 83.6% compared with 80.1% for linseed oil meal and 51.8% for hay.

The high protein content of the herbage consumed by grazing animals on good pastures is an indication of the need of supplementary feeds comparatively low in protein.

Palatability of pasture herbage is associated with the moisture content and the rate of growth. At Cornell University pasture herbage

harvested at a height of about 4 inches during the favorable grazing season of 1935 varied in its dry matter content from 22.2% to 33.3% during the grazing season. In the abnormally dry season of 1936 the variation was between 24.2% and 46.9%.

CONCLUSIONS

The successful improvement and management of pastures in the northeastern states involves the application of an adequate amount of phosphorus, supplemented by lime and potash on soils which respond to them. The large amount of nitrogen required is best obtained by the encouragement of pasture legumes, especially wild white clover. Yellow trefoil and wild birdsfoot trefoil are also of value. Close grazing with short periods of rest and the use of the mowing machine, flexible grass harrow, and roller are necessary for the proper development of the type of sward required.

The ideal sward for grazing purposes in the northeastern states is leafy, extremely dense, about 4 inches in height, and contains about 50% of wild white clover and other pasture legumes and 50% of desirable grasses of a definitely pasture type which grow actively during different periods in the grazing season. Such pastures enable a grazing animal to consume the maximum amount of total digestible nutrients each day and provide an adequate supply of minerals and vitamins.

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THE INFLUENCE OF STAGE OF GROWTH OF CORN ON THE COMPOSITION OF SILAGE[1]

R. G. WIGGANS[2]

CORN is preeminently *the* silage crop in America while the utilization of silage reaches its maximum in the northeastern section of the United States. For this reason this discussion will be confined entirely to corn and mostly to the corn plant before it enters the silo. The relative values of silages made from any crop depends almost entirely on the composition of the plants at harvest time. This, in turn, depends largely on the stage which has been reached in the life cycle of the plant. A study of the developmental phase or life cycle of the corn plant, therefore, becomes extremely important in any consideration of the silage problem as it exists in the northeastern United States.

There has been and still is a tendency in this area to grow special varieties for silage which produce large tonnages per unit area without too much consideration being given to the economic efficiency of such production. The choice of a proper variety involves not only tonnage per unit area, but also many other factors, such as cost of production per feed unit, feeding value per unit of silage, ability of the cow to consume a given quantity of feed units, and problems of ensiling.

The specific problem in the Northeast is not so much "when to cut a particular variety for the purpose of making the best silage", but rather "what is the type and variety best adapted to a given region for the production of silage." More emphasis must be placed on the second problem because the time of harvest is determined for the most part by weather conditions (date of first frosts) rather than the stage of development of the variety being grown. In the vicinity of Ithaca, New York, corn for silage must be harvested not later than September 15 to 25 if danger of material loss from frosts is to be largely eliminated. The tendency of the farmer is to harvest earlier rather than later to increase his margin of safety.

Excellent studies on the development of the corn plant, particularly in its later stages of growth, have been reported by many investigators, including Whitcher (16),[3] Schweitzer (15), Babcock (2), Ladd (13), Armsby (1), Jordan (11), Farrington (7), Jones and Huston (10), Ince (9), and Nevens (14). An excellent picture of the life cycle of the corn plant from before tasseling to maturity is presented by these investigations. Some of these reports were made on individual grain varieties adapted to the particular environment and were not designed to answer the problem in the region under consideration today; some answered very clearly certain questions essential in solving the

[1]Contribution from the Department of Plant Breeding, Cornell University, Ithaca, N. Y. Paper No. 218. Also presented before a joint session of the Northeastern Section of the Society and Section O of the American Association for the Advancement of Science held at Atlantic City, N. J., December 29, 1936.

[2]Professor of Plant Breeding.

[3]Figures in parenthesis refer to "Literature Cited", p. 467.

problems of today, while others gave conflicting results and questionable conclusions.

This is not the place to review these experiments in detail, but a few of the outstanding facts established by parallel findings of different investigators should be enumerated, as follows:

1. The percentage of dry matter increases with the advance in the life cycle of the plant.

2. Total dry matter production increases very rapidly after the ears have begun to form.

3. The maximum green weight is attained before the maximum dry weight.

4. Chemical composition of dry matter changes with the development of grain showing a decline in ash, protein, and crude fiber, and an increase in nitrogen free extract.

5. Late-maturing varieties will outyield earlier-maturing varieties in green forage and generally in dry matter production.

The feeding value of silages made from corns at different stages of development has been given attention by a smaller group of investigators, including Jordan, Bartlett, and Merrill (12), Armsby (1), Ewing, Smith, and Wells (3, 4, 5, 6), Hayden and Perkins (8), White and co-workers (17, 18, 19), and Nevens (14). Among the significant conclusions to be drawn from the various investigations on the feeding problems are:

1. The more mature corn has become when ensiled the more valuable the silage per unit weight.

2. The relative values of silages per unit weight of dry matter from corns of different maturity dates harvested at the same time or from successive harvests of the same variety approach equality.

3. Silage satisfactory from the standpoint of keeping, palatability, and digestibility can be made from corn at practically any stage of development; however, the more mature the corn when ensiled, provided it can be properly packed, the less the loss of dry matter in storage and the lower the acid content of the resulting silage.

The increased interest in pastures in particular and forage crops in general as indicated by the various activities of experiment stations and the U. S. Dept. of Agriculture has resulted also in a renewed interest in the silage problems of the region. Recent developments on the use of forage crops in the early stages of their life cycles, accompanied by studies on the chemical changes in young grasses, have likewise served to stimulate further consideration of the various phases in the most effective use of corn for silage purposes. Not only is a detailed knowledge of the complete life cycle of the plant to be ensiled necessary for a solution of the silage problem, but it is also fundamental to an intelligent corn breeding program which has for its object the development of a corn primarily for the purpose of producing silage. Especially are such studies necessary in a region handicapped by short growing seasons, limited heat units, long days, cool nights, late springs, and early falls.

In order to establish a better basis for the corn breeding work at the Cornell Agricultural Experiment Station, as well as to increase our information on the corn plant, an experimental study was carried

out. A part of the results of this investigation have a bearing on the problem under discussion.

PLAN OF THE EXPERIMENT

Four varieties, Early Huron, Cornell No. 11, Luce's Favorite, and Eureka, were chosen as representative of early, medium early, medium late, and late varietal groups. These varieties were harvested at 10- and 5-day intervals throughout their life cycle within their limits of use for silage in the region. Shrinkage samples of approximately 40 pounds were taken of each variety at each harvest, dried to constant weight at 185° F. The dry grain, if any, was determined together with the total dry matter.

All plats for the later cuttings were three rows wide with the central row used for yield determinations. Every fifth plat was a check, all of which were harvested on the same date and used as an aid in making comparisons between cuttings in the final calculations. The four varieties for each harvest were grown in adjacent plats since the comparisons between varieties were more important than the comparisons between harvests.

RESULTS OF THE EXPERIMENT

GREEN MATTER PRODUCTION

The 6-year average green matter productions expressed in yield per acre of the four varieties at 10-day intervals are given in Table 1. From the standpoint of green matter production, the four varieties are very distinct. Although approaching uniformity in performance until July 10, they show a wide difference after August 10. Until July 20 Eureka, the latest of the four types, was only equal in production to Early Huron; both, however, were lower than the other two Toward the end of the season all varieties lost green weight, the two earlier ones showing a loss starting 10 days sooner than the two later varieties.

TABLE 1.—*Six-year average total green matter production in pounds per acre of four corn varieties at scheduled dates during the growing season.*

Date of harvest	Eureka	Luce's Favorite	Cornell No. 11	Early Huron
June 20	461	586	444	346
June 30	1,392	1,834	1,581	1,292
July 10	2,918	3,867	3,442	2,897
July 20	6,359	8,654	7,551	6,333
July 30	12,759	15,119	12,153	9,843
Aug. 10	23,680	22,580	17,299	15,097
Aug. 20	30,856	26,365	21,096	17,552
Aug. 30	31,171	27,802	22,844	19,172
Sept. 10	34,247	31,846	24,923	19,889
Sept. 20	35,612	32,023	23,277	18,870
Sept. 30	35,051	30,357	21,242	16,587

PERCENTAGE DRY WEIGHT

A brief examination of Fig. 1 shows four things, as follows:

1. A continuous decrease in the percentage dry matter for about 30 days following the seedling stage.

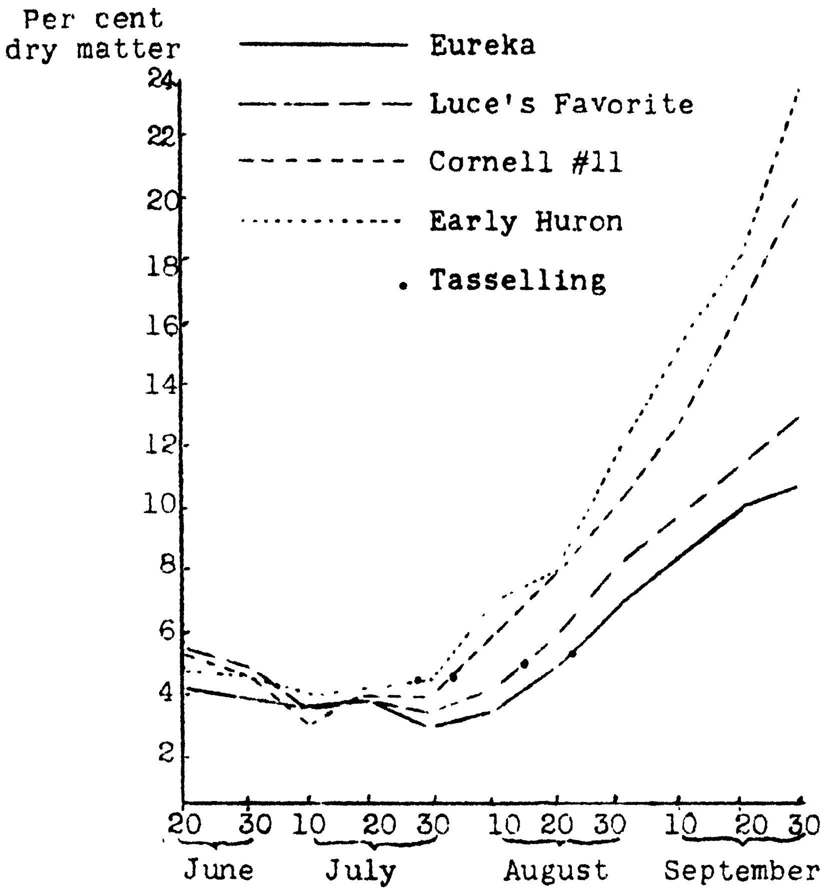

FIG. 1 - Six-year average percentage of dry matter at scheduled intervals from June 20 to September 30.

2. A continuous increase in percentage of dry matter in all varieties after July 30, the change increasing in magnitude as the plant advanced in maturity.

3. A fairly uniform percentage of dry matter at the tasseling stage regardless of variety.

4. A wide difference between varieties at any given date following July 20.

The graph represents the average of 6 years for the several dates, thus tending to minimize the change. To illustrate, the average drop in percentage dry matter as shown in the graph is 1.7 for the four varieties, while Table 2 shows the actual drop to average 2.9% for the four varieties. The table also shows decreases from 0.9% in 1922 to 4.9% in 1925. It is of interest to note that there is no exception regardless of variety or year to the fact that there is a drop in the percentage of dry matter. Farrington's and Schweitzer's data in particu-

lar also show clearly a marked decrease in percentage dry matter during the early stages of growth of corn.

TABLE 2.—*Percentage drop in dry matter from first cutting to minimum for four varieties of corn.*

Variety	1920	1922	1923	1924	1925	1926	Average
Eureka	2.1	0.2	0.6	3.1	5.7	5.3	2.8
Luce's Favorite	3.2	1.8	4.9	1.9	3.7	5.4	3.5
Cornell No. 11	2.6	1.3	3.7	2.8	5.9	2.7	3.2
Early Huron	2.1	0.5	2.7	0.2	4.4	2.7	2.1
Average.	2.5	0.9	3.0	2.0	4.9	4.0	2.9

The date at which the minimum percentage of dry matter occurs varies both with the variety and with the year. The average maximum difference between varieties is close to 15 days, varying from July 16 to August 1, as shown in Table 3. In general there is a fairly uniform difference between the varieties as far as the date of minimum dry matter content is concerned, although there was one outstanding exception to this rule in 1924. The percentage dry matter content during that year gave an irregular curve, showing two periods of depression, a phenomenon common to all four varieties but it happened that the two earlier-maturing varieties showed the lowest point during the first depression while the two later varieties showed the lowest point during the second depression. This made a very wide spread between the dates of minimum dry matter content between the earlier and the later varieties for that year. This exception causes the irregularity in the dry matter content curves as seen in the graph.

TABLE 3.—*Date of minimum percentage of dry matter for four varieties of corn.*

Variety	1920	1922	1923	1924	1925	1926	Average
Eureka	July 30	June 30–July 10	July 30	Aug. 15	July 30	Aug. 15	Aug. 1
Luce's Favorite	July 20–30	June 30	July 10	Aug. 10–15	July 30	Aug. 15	July 25
Cornell No. 11. . . .	July 20	June 30	July 10	July 10	July 20	Aug. 15	July 18
Early Huron	July 20	June 30	July 10	July 10	July 20	July 30–Aug. 10	July 16

The characteristic of corn in general which shows a decrease in dry matter content during the early stages of development may have no practical relationship with silage production but is of interest and may be of importance in considering the curing and use of grass plants in early stages of growth.

DRY MATTER PRODUCTION

The relationship of the harvested material to its moisture content determines the feeding value of silage within very wide limits. As previously pointed out, numerous investigators have emphasized the im-

portance of dry matter content in silage without too much reference to green weight, a matter which has not been given much consideration by the farmer to his disadvantage.

The dry matter production of the four types of corn under consideration in this report is shown in Table 4. Ten-day periods are again used to simplify the presentations. The remarkable parallelism between the four varieties is well illustrated. This is especially true up to the period at which the grain begins to be a consideration and, even in later stages, is in notable contrast to the growth curves based on green weight.

TABLE 4.—*Six-year average total dry matter production in pounds per acre for four varieties of corn at scheduled dates during the growing season.*

Date of harvest	Eureka	Luce's Favorite	Cornell No. 11	Early Huron
June 20	61	73	62	51
June 30	149	197	176	153
July 10	308	408	364	331
July 20	712	966	861	727
July 30	1,376	1,710	1,485	1,261
Aug. 10	2,787	2,861	2,552	2,349
Aug. 20	3,972	3,761	3,451	2,865
Aug. 30	4,723	4,522	4,221	3,872
Sept. 10	5,708	5,746	5,283	4,696
Sept. 20	6,381	6,202	5,725	5,028
Sept. 30	6,614	6,429	5,919	5,125

Special attention is called to the behavior of Luce's Favorite and Eureka, which almost coincide throughout the season. Luce's Favorite is probably significantly ahead of Eureka in the early stages while the latter shows a 3% greater production at the close, a difference of doubtful significance. Even if this difference were true, it would mean handling an excess of 1¼ to 1¾ tons of water for an equal amount of dry matter above that necessary when Luce's Favorite was used.

Cornell No. 11 is significantly lower in dry weight production than either Luce's Favorite or Eureka, while Early Huron is obviously out of the running as a type for silage under the conditions of the experiment.

In order better to understand what is taking place in the corn plant during its life cycle, a study of the actual production within given periods is presented in Tables 5 and 6. The data in Table 5 represent the 6-year average dry weight production in 10-day intervals throughout the season. The greatest dry weight production occurs, with one exception, during the first 10-day interval in August. Considerable irregularity in dry matter increase is shown, which may or may not be significant. The detailed data give indication that there may be some correlation between this lack of a uniform curve of production and the early stages of grain development; however, this is not clear.

From the standpoint of the physiologist the greatest efficiency in production, as measured by the dry matter added per unit of dry matter at the beginning of a time interval, occurs during the period of elongation, rather than the period of internal development. Gains

TABLE 5.—*Six-year average dry matter production in pounds per acre for four corn varieties during 10-day periods.*

Date of harvest	Eureka	Luce's Favorite	Cornell No. 11	Early Huron
June 20	61	73	62	51
June 30	88	124	114	102
July 10	159	211	188	178
July 20	404	558	497	396
July 30	664	744	624	534
Aug. 10	1,411	1,151	1,067	1,088
Aug. 20	1,185	900	899	516
Aug. 30	751	761	770	1,007
Sept. 10	985	1,224	1,062	824
Sept. 20	673	456	442	332
Sept. 30	233	227	194	97
Season's total	6,614	6,429	5,919	5,125

TABLE 6.—*Six-year average green matter production in pounds per acre for four corn varieties during 10-day periods.*

Date of harvest	Eureka	Luce's Favorite	Cornell No. 11	Early Huron
June 20	461	586	444	346
June 30	931	1,248	1,137	946
July 10	1,526	2,033	1,861	1,605
July 20	3,441	4,787	4,109	3,436
July 30	6,400	6,465	4,602	3,510
Aug. 10	10,921	7,461	5,146	5,254
Aug. 20	7,176	3,785	3,797	2,455
Aug. 30	315	1,437	1,748	1,620
Sept. 10	3,076	4,044	2,079	717
Sept. 20	1,365	177	-1,646	—1,019
Sept. 30	—561	-1,666	-2,035	—2,283
Season's total	35,051	30,357	21,242	16,587

of 200% by weight in a 10-day interval during the period of elongation is almost the rule while much smaller percentage increases occur later in the life cycle of the plant. On the other hand, the greatest efficiency in production as measured by the increase in a given time interval per unit area of land occupied occurs during the month of August and the first 10 days of September, a period during which the dry matter production approaches constancy when an average for the period is the measure. This is true regardless of the variety. The slowing down in production in succeeding time intervals is somewhat less rapid in the later maturing varieties than in the earlier varieties.

In Fig. 2, where the increase in time interval is expressed in percentage of the total production, these points are more easily visualized. The increase of the several varieties in the first five 10-day time intervals is very regular, being influenced less by weather conditions, particularly the water factor, than later periods. Again there is strong indication of some influencing factor which is more or less constant in causing a slowing down of dry weight production just after polli-

nation with a succeeding period of greater activity. This can not be established as a fact by the data available from this experiment.

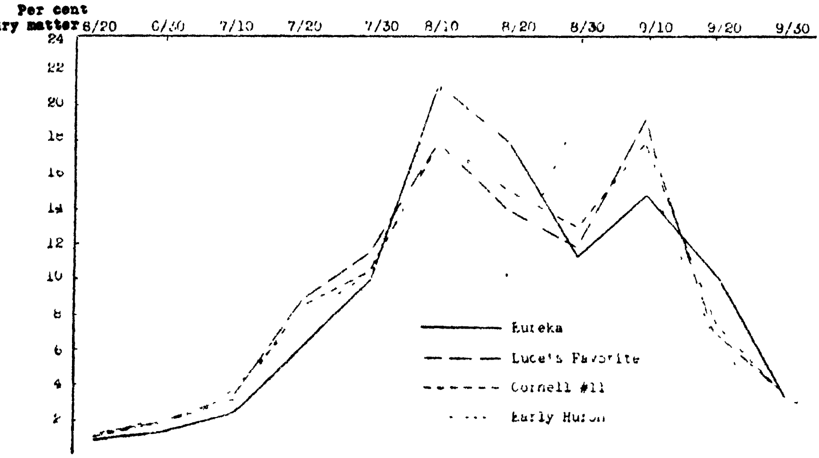

FIG. 2. Six-year average dry matter production during 10-day periods expressed in percentage of total.

Table 6 shows the 6-year average green weight production during the same period. Without exception the same 10-day interval in August shows the greatest increase. Following this period there is a rapid falling off with a material loss as the plant matures.

GRAIN IN THE DRY MATTER

As already pointed out, there is little convincing evidence of any considerable difference in the feeding value of silage made from varieties of corn of different maturities if based on the dry-matter content, but a decided difference if based on green weight. The greater feeding value in a unit quantity of fresh silage made from the more mature corn as compared with silage made from less mature corn has caused many feeders to conclude that the grain in the silage is the important factor. It is difficult to verify this point; in fact, there is considerable argument to the contrary. Nevertheless, the amount of grain in the silage is of much interest and is always a rough measure of the amount of water present at harvest and consequently of the tonnage necessary for a given amount of food value. The data on the percentage of dry shelled grain in the dry matter content at various harvest dates of the four varieties of corn under consideration are presented in Fig. 3.

Fig. 3 shows (a) the wide difference in percentage dry matter between the varieties at all dates after August 20, (b) the late date in the appearance of grain in the case of Eureka, and (c) the rapid and uniform increase in the ratio of grain to total dry matter.

It is the percentage of grain in the dry matter of these varieties at the different harvest dates that shows best the relationship between maturity and variety and that the varieties chosen were well within

the group of corn varieties which they were supposed to represent. Eureka fails to show any grain before September 25, the end of the safe harvest period in the region, while Luce's Favorite shows 10 to

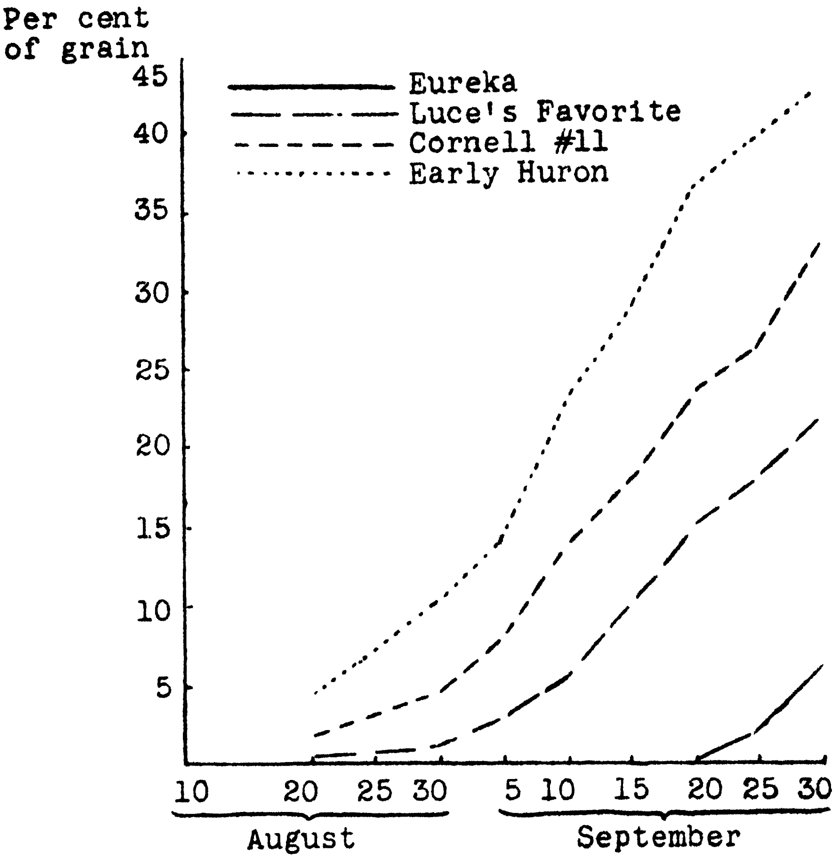

FIG 3.—Six-year average percentage of dry shelled grain in total dry matter for four varieties of corn of widely different maturity dates at scheduled intervals from August 20 to September 30.

18% of the dry matter to be grain during the harvest period, Cornell No. 11, 18 to 26%, and Early Huron, 28 to 39%. The continuous and almost uniform increase in percentage of grain in the dry matter is in contrast to the development of percentage of total dry matter as already shown.

The actual dry shelled grain in the harvested material is shown in pounds per acre in the upper half of Table 7, while the increase per uniform time interval is shown in the lower half of the table.

These data show the exceedingly rapid development of grain during the month of September. If calculated, these increases will be found to amount to 100% of the total for Eureka, 97% for Luce's Favorite, 90% for Cornell No. 11, and 82% for Early Huron. Prob-

TABLE 7.—*Dry shelled grain based on a 6-year average for four corn varieties.*

Date of harvest	Eureka	Luce's Favorite	Cornell No. 11	Early Huron
	Total, Lbs. per Acre to Date of Harvest			
Aug. 20	0	11	55	123
Aug. 30	0	45	186	399
Sept. 10	0	328	734	1,071
Sept. 20	0	930	1,351	1,820
Sept. 30	410	1,414	1,941	2,183
	Production in Lbs. per Acre Between Harvests			
Aug. 20	0	11	55	123
Aug. 30	0	34	131	276
Sept. 10	0	283	548	672
Sept. 20	0	602 (146)*	617 (175)*	749 (417)*
Sept. 30	410 (177)*	484 (257)*	590 (396)*	363 (266)*

*Translocated from previously elaborated material.

ably the most interesting part of the data on the grain in these silage corns is concerned with its development during the last 20 days of the experiment. With the exception of Eureka where there was no grain by September 20, the greatest total grain was laid down during the period of September 10 to 20 and there was only a little falling off from this maximum in the last 10 days with both Luce's Favorite and Cornell No. 11. If these data are compared to the data on the total dry weight development, the increases in grain will be found to be greater during the last two periods than the increase in total dry matter. The differences between these corresponding data are given in parenthesis. These amounts must represent not dry matter development but dry matter transfer, a translocation of previously elaborated plant material. All of such transfer, which amounts to 43, 53, 67, and 73% of the total production according to the variety during the last 10 days of September means a loss of feed value in the stalk and a concentration in the ear, a difference of very doubtful value in silage. In fact it would seem to be a disadvantage, particularly if any part of the transfer was laid down in the form of *mature grain*, a portion of which is often lost due to the inability of the animal to digest the whole grain completely. It would seem, therefore, that the period of greatest efficiency of the corn plant in the production of digestible material is passed by the time the grain is one-half developed.

CHOICE OF A VARIETY FOR SILAGE

It is not the purpose of this paper to discuss all the problems involved in the matter of choosing a variety of corn for silage even if satisfactory information were available. The chemical changes taking place in the plant offer an interesting field of speculation and research. The economic problems are just as interesting. The relationship of the amount of water handled to a unit of dry matter harvested is indicated in Table 8. Among other problems of importance are relative costs of silage and other forms of feed, and speculations

TABLE 8.—*Excess pounds of water handled per acre for equivalent dry weights (4,000 pounds), using Cornell No. 11 on September 20 as the base.*

Date of harvest	Eureka	Luce's Favorite	Cornell No. 11	Early Huron
Aug. 25	13,458	11,193	7,559	6,334
Aug. 30	10,634	8,298	5,585	3,809
Sept. 5	8,452	6,596	3,809	2,386
Sept. 10	7,997	6,079	2,838	848
Sept. 15	7,136	4,771	1,707	414
Sept. 20	5,829	4,332	0	−889
Sept. 25	5,465	3,119	-1,241	2,647
Sept. 30	4,997	2,746	2,209	-3,654

as to the future of silage, none of which can be undertaken here. However, the following conclusions seem justified from the summary data which have been presented:

1. The later the variety of corn grown is in maturity, the larger will be the green weight production provided the plant has passed the flowering stage.

2. Early maturing varieties are not only higher in dry matter percentage but are higher in total dry matter production than later varieties during the period of elongation.

3. The period of rapid green matter production is relatively much shorter than the period of rapid dry matter production.

4. Dry matter production of corn varieties varying widely in maturity dates, although showing differences, is not as widely separated in production of feeding units as is ordinarily considered by silage producers.

5. The percentage of grain in the dry matter of the varieties under consideration varied from 0 to 36.2% on September 20.

6. Grain produced after September 20 is largely produced at the expense of previously elaborated plant material.

7. Extremely late varieties of corn for any given region, varieties which will produce little or no grain by the ideal harvest date, are unsuited for silage purposes. Similarly, varieties which show material slowing down in the production of dry matter before the middle or end of the silage harvest period due to advanced maturity are too early to give the best results in silage production.

8. The best variety for silage purposes lies somewhere between the two extremes and can be described as "a variety which utilizes the growing season to the best advantage in the production of dry matter but at the same time reaches, at least 3 years in 5, a stage of maturity which may be loosely described as the dough stage." Such a variety will have utilized the greater portion of the period of internal development which is extremely efficient in dry matter production, will contain a satisfactory percentage of dry matter, will not have reached the stage where grain is developed primarily at the expense of the stored material in stems and leaves, and will give a yield of dry matter approaching the maximum for corn under a given set of environmental conditions.

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TECHNIC IN PASTURE RESEARCH[1]

B. A. Brown[2]

TECHNIC in pasture research is an extremely broad subject. Not only does it include most of the agronomic research methods, but also, as the word "pasture" implies, is directly concerned with animals. Thus, in pasture research, we must take into consideration the effects of numerous factors on the pasture and on the grazing animals and also the effects of animals on the pasture. Even if the author were capable of discussing intelligently the endless details involved in pasture research, space will not permit such a discussion in this paper. For many pasture research situations, the report of the joint committee of the dairy and animal husbandry specialists and agronomists gives procedures that had the general approval of experienced investigators. Therefore, such important phases of technic as uniformity in the physical and chemical characteristics of soil; replication, size, and shape of plats or other cultural units; repetition over a period of years to obtain a representative cross-section of the weather; and the need for care in performing all operations, will not be discussed here. This paper will be confined to a few topics peculiar to this relatively new subject, "pasture experimentation".

GRAZING VERSUS MECHANICAL HARVESTING OF HERBAGE

In farm practice, the primary difference between pasture and other forage crops is that the former is harvested by animals, the latter by tools or machines In pasture research, both methods are employed. It is pertinent to inquire what significance the data from machine-harvested plats have. No one knows the answer, but there are available some interesting facts.

Animals exercise preferences both for kinds and parts of plants in their grazing. For example, Stapledon (7)[3] found that sheep ate much more of some species than others and more leaf than stem in all species. As a consequence of animal preferences, the herbage of grazed and mowed plats may, in time, differ markedly in botanical composition. The importance of these differences would depend on many factors, including the type of sward and animal, the time and rate of stocking, and soil fertility or fertilization.

Animals void a large proportion of the fertilizer elements consumed in their feed. This is particularly true of nitrogen and potassium. That the previous use of the land may have a very important bearing on its response to fertilizers may be illustrated by some observations made at the Storrs Agricultural Experiment Station. There, a meadow runout by the mowing and removal of hay crops responds

[1]Contribution from the Department of Agronomy, Connecticut (Storrs) Agricultural Experiment Station, Storrs, Conn. Also presented before a joint session of the Northeastern Section of the Society and Section O of the American Association for the Advancement of Science at Atlantic City, N. J., December 29, 1936.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 476.

markedly to potash, while an adjacent pasture, runout by grazing, shows little, if any, more growth of herbage when that nutrient is included in the fertilizer.

Different classes of livestock remove varying amounts of fertilizer elements from the soil. For instance, fattening animals require less N, P, and Ca than milking or growing stock. Milking cows are usually removed from the pasture for several hours, frequently for all night, and other parts of the farm benefit from the voidings at the expense of the pasture. It is common observation that night pastures are superior to day pastures. As far as research technic is concerned, the results of grazing experiments should have more local application if the class of animals prevailing in that region are used to measure production. However, there is some danger, particularly in fertilizer experiments, in following this general rule. Milking cows usually receive more or less supplemental feed and indirectly the pastures receive elements not derived from the fertilizers. The relative effects of the manure may be expected to vary inversely with the adequacy of the direct fertilization. With optimum fertilization, no benefit and possibly only harm would result from the extra manure derived from supplemental feeds. As these varying effects cannot be evaluated, it appears to be good experimental procedure to reduce supplemental feeding to the lowest possible minimum.

In the Storrs experiments,[4] yearling Shorthorn steers were used the first 11 years for grazing and dairy heifers the last 5 years without appreciable differences due to kind of animals appearing in the relative productions of the several pastures.

Several stations in the northeastern United States have obtained data showing a high correlation between grazed and mowed yields. The Pennsylvania Experiment Station (3) has published the yields of digestible nutrients from grazing 24 2-acre pastures for 2 years with heifers and 3 years with milking cows and from the clippings of protected areas in the same pastures. As calculated, grazing gave between 70 and 80% as many digestible nutrients as the clippings. There was a high positive correlation between them. However, as the mowed inclosures are changed to previously grazed areas every two to three years, this experiment does not afford a comparison between continuously mowed and continuously grazed land.

The West Virginia Experiment Station (6) has also found high positive correlations over a 5-year period between the yields of clipped permanent and moved caged areas and the production of feed as measured with milking cows. Nevertheless, the yields of total digestible nutrients from continuously mowed areas have gradually decreased and were only 56% of the grazed plats in 1936. The corresponding percentage as determined by the "difference" method was 119. It will be interesting to follow the results over a longer period.

At the Storrs Station the relative yields of dry matter from continuously caged areas were greater in most cases than the corresponding yields as determined by grazing with dairy heifers without supplemental feed. The yields of the differently fertilized pastures were in the same order by either method (Table 1). However, in all cases, the

[4]Unpublished data.

continuously clipped cages have yielded less than the annually moved cages, although the differences have not been significant in some instances as indicated by the data in Table 2.

TABLE 1.—*Relative yields of permanent pastures as measured by grazing or by clipping continuously caged areas.**

Plat	Fertilization	1931		1932		1933	
		Grazed	Clipped	Grazed	Clipped	Grazed	Clipped
5	None	100	100	100	100	100	100
8N	PLK	284	234	213	415	244	448
6N	PLKN	386	284	238	523	360	532
		1934		**1935**		**1936**	
		Grazed	Clipped	Grazed	Clipped	Grazed	Clipped
5	None	100	100	100	100	100	100
8N	PLK	182	208	259	431	182	229
6N	PLKN	326	279	349	579	284	312

[illegible] gains in weight of dairy heifers (steers, 1931) and the relative clipped yields on pounds of dry matter in the herbage from eight cages, 3 feet square, in each 2-acre pasture.

TABLE 2.—*The effects of continuous mowing on yields of permanent pastures.*

Plat	Fertilization	Relative yields of dry matter from annually moved cages if continuously clipped cages equal 100*				
		1932	1933	1934	1935	1936
5	None	193±15	254±28	210±22	182±10	281±37
8N	PLK	145±11	131±6	161±10	129±7	182±15
6N	PLKN	113±9	120±4	150±6	114±7	122±5

*Continuously clipped cages were placed on pastures in 1931

Because of the substantial agreement between grazed and cut yields at three experiment stations, many may assume the results furnish sufficient evidence that machines may safely replace animals in the harvesting of herbage from the various cultures in pasture experiments. But one need only recall the great differences found in the physical and chemical composition of the soil and the botanical composition of the vegetation between old non-tilled pastures and tilled reseeded grass land, to feel there is much danger in this assumption. We have noted distinct differences in the response to fertilizers of land never tilled and adjacent areas where tillage operations stopped 45 years ago. The agreement might be expected to become closer as fertilization approached the optimum, provided, of course, there was not much waste in grazing.

Probably the factor of change in soil characteristics due to tilling can be disregarded in the case of rotation ("short ley") pastures. Here, however, the factor of animal preference in grazing may have a stronger influence on the botanical composition than in permanent pastures.

There are certain other situations where erroneous conclusions might be drawn from mowed yields, even when rather complete chemical analyses are performed on the product. One is illustrated by the results of Crampton's (1) rabbit feeding experiments, in which it was found that reed canary grass, although containing fully as much *total* protein, was, because of its deficiency in one of the essential amino acids, a much poorer feed than timothy. Another example is furnished by the Storrs experiments where the production as measured by growing heifers has not increased in proportion to the increases in the yields of protein induced by certain fertilizers.

Some investigators have determined yields by cutting small protected areas rotated on each of the unfenced test units. This method combines the advantage of measuring the growth of grazed land with the cheapness of "cut" yield measurements. Nevertheless, it has one very objectionable feature, namely, that without fences there is bound to be unequal grazing of the differently treated plats, thereby probably introducing larger errors than those presumably eliminated by this scheme. If uniform grazing is enforced by fencing, it would be but little more trouble to conduct a real grazing experiment and eliminate the measurements of yields by cutting. The clipping of caged areas does afford a reasonably accurate method of determining the production of fenced pastures varying only in one of such factors as soil type, direction of slope, fertilization, or botanical composition.

MANAGEMENT OF GRAZING EXPERIMENTS

The time and rate of grazing are important factors in the performance of a pasture. Thus, we have obtained over twice as much production, as measured by heifers, from starting grazing May 5 as June 10, and this in spite of the fact that a much higher yield of dry matter was produced where pasturing was delayed until June (Table 3).

TABLE 3.—*Yields as influenced by date of first grazing in the spring.*

Date of first grazing	Feed units (therms) per acre*						
	Total	Before May 16	May 16-June 15	June 16-July 15	July 16-Aug. 15	Aug. 16-Sept. 15	After Sept. 15
May 5	1,431	257	412	318	206	123	115
May 15	1,163	231	362	235	118	147	70
May 27	718	118	210	133	119	87	51
June 10	601	110	217	82	95	74	23

*Average results on J, 1933–1935.

To obtain the greatest possible growth from permanent pastures under mineral fertilization in humid temperate regions, it is extremely important that wild white clover occupy from 20 to 40% of the area. Unless such pastures are grazed quite closely in May and June, the proportion of clover is liable to be much below the desired amount and an entirely false conclusion might be drawn as to the benefits of the fertilizer.

In the far west, where pasture species maintain their stands chiefly by natural reseeding, it is necessary to graze very leniently every fourth year during the seed-producing period.

CALCULATION OF PRODUCTION

The yields of grazed pastures should be expressed in terms of some common feeding unit, such as total digestible nutrients or therms, using the available standards for the class of animals in question. Until recent years, standards for growing dairy heifers were not available, but in 1931, Eckles and Gullickson (2) published a useful paper on that subject. We have calculated the results from grazing over 20 experimental pastures for 5 years with dairy heifers by Armsby's thermal and the Eckles' total digestible nutrient standards. In general, these two methods have given very similar results, but there have been a few cases where differences of 15% have occurred. Apparently these discrepancies are partly due to differences in emphasis on maintenance and gains. Armsby's standard gives relatively more credit for increases in weight. Therefore, if experimental pastures were not stocked at the same rate and as a result the animals gained more in one than in another, then that pasture would have a larger production by the Armsby than by the Eckles standard.

YIELDS DETERMINED BY CUTTING

Three general methods have been employed for cutting, *viz.*, (a) clipping with grass shears, (b) cutting with lawnmowers, and (c) mowing with machines used in the harvesting of hay. Hand plucking has been used but seems both too laborious and too dependent on human judgment to be given serious consideration. Naturally, no one of the three methods is superior for all conditions. The choice depends on the area to be cut, the topography and smoothness of the land, and particularly on the species. Grass shears are useful chiefly for clipping very small areas, such as in cages, quadrats, nursery rows, etc. With shears, the height of the plants is not a very important consideration. This is not true of lawnmowers, especially those with only a narrow range of adjustment in height of cutting. For herbage not over 6 inches high, the ordinary hand or motor-driven lawnmowers, with grass catchers, are very useful and when properly adjusted, more nearly approach actual grazing conditions than either shears or mowing machine. For effective work, the land must be quite free of irregularities and stones. With the motor-driven type it is desirable to have separate means of acceleration for the blades and the wheels so as to cut thick herbage cleanly without clogging.

The ordinary mowing machine is the most suitable for cutting larger vegetation. It may be argued that pasturage should never be allowed to reach a height beyond which a lawnmower cannot cut efficiently. This may be true of sward-forming species like Kentucky bluegrass or Bermuda grass. However, the yields of certain species cannot be measured by any mowing method that cannot handle herbage 10 inches or more in height. For example, a good stand of alfalfa

cannot be maintained if mowed before the blooming stage. It would be difficult if not impossible to cut Sudan grass and other annuals with a lawnmower.

There is much evidence showing that as height of herbage when cut (or grazed) is reduced, the yields are also decreased. Although, as pointed out earlier, harvesting may be delayed so much that the nutritive value and white clover are greatly diminished, available information does not warrant standardization on very frequent or very close cuttings, even for species that will maintain good stands for long periods under such management.

HERBAGE SAMPLES

For a reasonable degree of accuracy in determining yields by cutting, the herbage should be weighed and a representative portion saved for determination of dry matter. The importance of this procedure may be illustrated by the fact that we have found different species cut with a lawnmower on adjacent plats varying from 12 to 39% dry matter during a single month. To determine the dry matter in thousands of samples each year without drying them all to complete dryness in an oven, we have adopted the scheme of drying all samples quickly in a heated room, then removing them to unheated storage where they are kept for a few days to permit them to reach equilibrium, and finally weighing a large number of similar samples on one day, taking two or three for complete drying in an oven. We have found that the duplicate or triplicate air-dry samples taken for complete drying contain practically the same amount of moisture on any given day.

Excepting deficiency areas, the determination of dry matter is perhaps the most important one to make for *young* herbage, which usually contains enough protein and minerals for most classes of animals. With more mature vegetation, however, dry matter yields alone may lead to very inaccurate conclusions regarding its nutritive value. Of course, this is also true of other forage crops.

Analyses of feed and fertilizer constituents should, as far as possible, be performed according to methods approved by the American Association of Official Agricultural Chemists. Frequently, such analyses help to explain certain soil and plant relationships and even causes of malnutrition in animals. However, animals seem able to make about the same response to feeds varying considerably in chemical composition and therefore exact interpretations of many chemical analyses into terms of animal production will have to await further advances in the field of nutrition.

There are many cases where special care or methods must be employed in handling samples. For instance, in determining the forms of N existing in plants, very rapid drying or immediate plunging into hot water are considered necessary to prevent enzymatic or other changes in the plant during the drying process. We have found a slight loss of ammonia occurs when young grass is placed immediately in an oven at 95° to 100° C.

BOTANICAL COMPOSITION

The marked differences commonly noted in the botanical compositions of grassland, due to small variations in environment, are interesting and sometimes mysterious phenomena. Several methods of measuring such differences are in use. None of the methods is the most satisfactory for all regions. In the bunch grass areas of western United States, it is practical to make counts of the species in quadrats. Hanson and Love (4) concluded from their studies in Colorado pastures that 2 square meters, lying adjacent to each other, was the most suitable size for their conditions. In humid regions where dense swards of stoloniferous species predominate, it is almost impossible to make accurate counts and also requires too much time. Therefore, most workers have adopted one of the more practical methods. Probably the most common one in use is to estimate the percentage of area occupied by each species. In very small plats one estimate can be made for the entire plat, but for larger areas estimates should be made on a number of randomly selected spots. There is very little information on the degree of accuracy resulting from varying numbers and sizes of such spots. Important factors are the size of the plat and the uniformity of occurrence of the plants. A light frame, about 1 foot square, is thrown on the ground at approximately regular intervals over the plat and the area occupied by each species is estimated. It is considered helpful and more accurate to divide the square by cross wires and make estimates for each small square. In southeastern United States, it is advisable to make estimations on large rectangles because large areas are occupied exclusively by either Bermuda or carpet grasses.

The "point contact" method of Levy and Madden (5) is preferred over the ground cover estimates by Hanson and Love (4) for situations where exact counts are not practical. The method is in use in northeastern United States and some feel it is more accurate and not much slower than the ground cover estimates.

At Storrs, we have used the ground cover estimates almost entirely, and though we consider the method far from accurate, such marked and rapid changes have occurred in the prevalence of important species that we do not feel justified in making more accurate determinations. However, we do think that estimations should be made at least twice each season and on many of our small plats estimations of some species are made at each cutting.

At the Welsh Plant Breeding Station the species from many cultures have been separated and weighed after cutting. This, of course, is a very tedious task and also one requiring people trained to recognize the different plants. If combined with chemical analyses, the method is particularly valuable for determining the contribution of each species to the pasturage, a factor not evaluated by any of the other methods. The proportions of stem and leaf have also been measured by the Welsh workers. Whether a chemical analysis of the entire sample to determine its relative nutritive value would be a more practical scheme, is a pertinent question. In concluding the discussion of this topic, the opinion is advanced that very accurate de-

termination of botanical compositions frequently consumes time better devoted to learning the causes of such variations.

SEEDS AND SEEDING

The number of viable seeds planted affords little information as to the percentage of establishment (8). This is particularly true of mixtures. It has been a common practice to include small amounts of seed of some species which, because of poor establishment, might just as well have been omitted.

It should be recognized also that seeding at different dates favors certain species and penalizes others. In general, clovers are favored by spring and grasses by late summer or early fall seeding

SOIL SAMPLING

In many circumstances, the ordinary methods of sampling soils are not suitable for grass lands. This is particularly true of untilled land where fertilizers are applied on the surface. N, P, K, and Ca are frequently added to soils and of the four all except N penetrate slowly, while P in the soluble carriers remains very near the surface. Moreover, in humid regions at least, most of the roots of grasses are found in the upper 3 or 4 inches of soil. Therefore, it is frequently desirable to obtain samples of soil by 1- and even ½-inch layers. A soil augur cannot be used for such work. Holes dug with a spade usually furnish less representative samples and also have the additional disadvantage of disturbing more area.

A steel pipe, 2 inches in diameter and 30 inches long, sharpened and slightly drawn in at one end and perforated for a removable cross bar near the other end has been used for grass land sampling at Storrs. If the soil is moist and not too stony or sandy, cores 8 inches long can be obtained and slid intact from the upper end of the pipe. Such cores can be sliced into the desired number of divisions.

In studying changes in soils over a period of years, it is very important to take the samples at approximately the same dates. For annual or less frequent sampling, a date should be chosen when microbiological activities are at a minimum. April or November are thought to be the best months for such work in northern United States.

It is debatable whether soil samples should be tested at once or held until the end of an experiment. The pH and possibly other characteristics change somewhat in storage. If analyses are made soon after sampling, it may be inpractical or impossible to duplicate later the methods used earlier. In either case, samples should be held until there is little chance of being of further use.

FERTILIZATION

The fertility requirements of few, if any, species are well established. Many species have a wide range over which they thrive. Therefore, strain and variety tests should be conducted under several levels of fertility. As N is the most expensive element in common fertilizers, special pains should be taken to develop technics favoring legumes. However, for measuring the potential total and seasonal

yields of grasses in northeastern United States or regions with similar conditions, the writer believes nitrogenous fertilizers should be applied three or more times a season. This practice greatly discourages volunteer species, especially wild white clover (*T. repens*). Physiologically acid carriers of N are more effective in decreasing many herbaceous weeds and clover, but their use may be overdone with subsequent injury to the grasses. Soil tests will help in avoiding this danger.

Numerous topics have not been discussed in this paper. The breeding of grasses and legumes is one. Photography as an aid in measuring and depicting changes is another. Also, it is evident that exact knowledge is not available in many lines of pasture research and it is hoped this discussion will help in stimulating more thought and work on such phases.

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THE CALCIUM AND PHOSPHORUS CONTENT OF PASTURE HERBAGE AND OF VARIOUS PASTURE SPECIES AS AFFECTED BY FERTILIZATION AND LIMING[1]

W. H. PIERRE and R. R. ROBINSON[2]

THE chemical composition of pasture vegetation and the influence of fertilization on such constituents as calcium and phosphorus are of interest from two main points of view. To the animal husbandman the calcium and the phosphorus contents of herbage are recognized as important criteria of quality, whereas to the agronomist they may serve as a guide to a sound pasture improvement program, as well as to a better understanding of various soil-plant relationships.

As shown by Orr (31),[3] the problem is an old one. Müller (29), in 1873, suggested the chemical analysis of German pasture vegetation as a means of determining the feeding value and also the fertilizer needs of the soil. Few studies were made in this country, however, until after the discovery by various workers (8, 11, 18, 19, 21, 35) that the low phosphorus or calcium content of vegetation is responsible for various malnutrition troubles or deficiency diseases with cattle. Maynard (27), Orr (31), Eckles, *et al.* (11), and Henderson and Weakley (20) have thoroughly reviewed the work on this subject, and it need only be mentioned here that deficiency diseases, traceable to a low phosphorus or calcium content of the hay or pasture, have been reported from Minnesota, Wisconsin, Michigan, Montana, Texas, Alabama, and Florida in this country, as well as from many foreign countries.

So far as the writers know, no deficiency diseases with grazing animals have been reported in the northeastern states. Archibald and Bennett (2), however, found certain Massachusetts pastures to have a phosphorus content near the level found in vegetation where deficiency diseases occur. Similar results for certain New York pastures have been reported by Cooper and Wilson (9). It should also be recognized that mineral levels in vegetation may be high enough to prevent deficiency diseases but insufficient to insure maximum growth and development.

Various workers in this country (5, 6, 7, 14, 25, 28, 37) have reported an increased percentage of calcium and phosphorus in the vegetation of pastures treated with lime and phosphate fertilizers. Du Toit and Malan (10) point out, however, that, "The general principle that the mineral content of the soil is reflected in the mineral content of the vegetation growing upon it is true, but this must not be taken to mean that the mineral content of a pasture can be increased by applying fertilizer to a soil. What probably does happen is that on a soil rich

[1]Cooperative investigations of the West Virginia Agricultural Experiment Station and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Also presented at a joint session of the Northeastern Section of the Society and Section O of the American Association for the Advancement of Science at Atlantic City, N. J., December 29, 1936. Scientific Paper No. 185 of the West Virginia Agricultural Experiment Station.

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[3]Figures in parenthesis refer to "Literature Cited", p. 496.

in minerals, grasses which naturally show a high percentage of minerals will flourish at the expense of those which are normally able to thrive on a poorer soil." On the other hand, work by Forbes, *et al.* (14) with Kentucky bluegrass; by Brown (7) with sweet vernal grass, Kentucky bluegrass, and white clover; and by Vinall and Wilkins (37) with bluegrass and white clover show definitely that both the phosphorus and the calcium content of these species can be materially increased by field rates of application of superphosphate and lime.

According to a recent survey of West Virginia pastures (33), poverty grass (*Danthonia spicata*) and broomsedge (*Andropogon virginicus*) are the two most common native species present in untreated pastures. Cooper and Wilson (9) found that samples of poverty grass obtained from typical poverty grass pastures in New York were much lower in phosphorus, although somewhat higher in calcium, than were samples of Kentucky bluegrass obtained from bluegrass pastures. No work has been reported, however, relative to the mineral content of these species when grown under identical soil conditions. It is evident, therefore, that not only are more studies needed on the mineral content of pasture herbage in various areas and under various conditions as pointed out by Maynard (27), but more information is necessary regarding variation in composition of different pasture species as affected by soil fertility.

For the past 7 years pasture fertilization and liming studies have been conducted at the West Virginia Agricultural Experiment Station in cooperation with the Bureau of Plant Industry, U. S. Dept. of Agriculture. Since these experiments have been located on widely different types of pasture, they have afforded a good opportunity to investigate the influence of fertilization on the chemical composition of pasture vegetation. The objectives of this phase of the investigation were as follows:

1. To determine the influence of fertilization and liming on the calcium and phosphorus content of the herbage of a good and a poor pasture at different times during the season and for various years after fertilization.
2. To compare the calcium, phosphorus, and nitrogen content of Kentucky bluegrass, white clover, poverty grass, and broomsedge when grown in association and as affected by fertilization and liming.

EXPERIMENTAL PROCEDURE

The three areas selected for the study are briefly described in Table 1. Most of the studies, however, were conducted at Morgantown and Moorefield. The area at Morgantown is located on an unproductive upland soil, whereas the one at Moorefield is on a fertile bottomland soil. In the spring of 1930 these areas were divided into 0.002 acre plats and topdressed with various combinations of fertilizer and lime in quadruplicate. The legend for these treatments is given in Table 2. The plats were clipped with a lawn mower and the yields of dry forage determined. The frequency of clipping depended largely upon the rainfall, but ordinarily four to six clippings were made during the season. A detailed report of the yields as well as the changes in pasture flora obtained in this experiment will soon be available in a station bulletin.

The data reported in this paper represent the analysis not only of certain of the samples of clipped herbage but also of samples of white clover (*Trifolium repens*), Kentucky bluegrass (*Poa pratensis*), bromsedge (*Andropogon virginicus*), and

TABLE 1.—*General description of the pasture areas studied.*

Location	Soil type	Origin of soil	Chemical properties of the 0 to 3-inch soil layer		
			pH	PO_4, p.p.m.	Total N %
Morgantown, W. Va.	Dekalb silt loam	Residual from shale and sandstone	4.9	15	0.184
Moorefield, W. Va	Huntington silt loam	Wash from upland shale, sandstone, and limestone soils	5.8	32	0.211
Maidsville, W. Va.	Westmoreland silt loam	Residual from shale, sandstone, and limestone	5.6	21	0.194

TABLE 2.—*Fertilizer and lime treatments of the experimental pastures.**

Symbol	Fertilizer and lime (per acre)
P	500 pounds of 20% superphosphate in 1930 and in 1932
2P	500 pounds of 20% superphosphate in 1930, 1931, 1932, and 1933
K	100 pounds of muriate of potash in 1930 and in 1932
N	200 pounds of nitrate of soda per year, applied half in the spring and half in midsummer†
2N	400 pounds of nitrate of soda per year, applied half in the spring and half in midsummer
Ammo-phos	Ammo phos A and B every spring in amounts equivalent to 250 pounds of 20% superphosphate and 200 pounds of nitrate of soda
L (Moorefield)	2,550 pounds of ground limestone in 1930‡
L (Morgantown)	2,800 pounds of ground limestone in 1930‡ In 1933, 1,100 pounds were added to the plats that received no nitrogen. The amounts added to the plats that received nitrogen fertilizers were adjusted in accordance with the equivalent acidity or basicity of the fertilizer (32)

*All treatments are in quadruplicate

†In a few cases, as indicated in Table 11, the nitrogen carrier was sulfate of ammonia, but an equivalent amount of nitrogen was applied.

‡The limestone had a calcium carbonate equivalent of 80%

poverty grass (*Danthonia spicata*) collected just prior to certain of the clippings The samples of pure species were plucked by hand when the plants were in the vegetation stage of growth, unless indicated otherwise. The samples were dried, ground, and analyzed for calcium and phosphorus.

The laboratory procedure was as follows: One gram of plant material was moistened with 2 cc of 2N Na_2CO_3, evaporated to dryness, and ignited for 1 hour at 1,000° F. The residue was moistened with water, dried, and again ignited for 1 hour at 1,000° F. The ash was taken up with 20 cc of water and 5 cc of approximately 2N HNO_3 and made up to 100 cc. Aliquots of this solution were used for the determination of both calcium and phosphorus. Calcium was determined essentially by the method of Kramer and Tisdall (23) and phosphorus by the method of Fiske and Subbarow (13). All chemical analyses are reported on the basis of the air-dry samples, which contained approximately 6 or 7% moisture.

CALCIUM AND PHOSPHORUS IN PASTURE HERBAGE

The mineral content of the pasture herbage is dependent not only upon soil and climatological factors and the maturity of the plants, but also upon the botanical composition of the pasture. At the time the experiment was started the botanical estimates for the Morgantown area averaged 58% undesirable grasses (poverty grass with smaller percentages of broomsedge), 19% weeds (largely cinquefoil, yarrow, and antennaria), 14% Kentucky bluegrass and red top, 2% white and red clover, and 7% bare space. During the course of the experiment there was a marked increase in the percentage of weeds and bare space on the untreated plats and a corresponding decrease in the percentages of grasses and clover. On the limed and fertilized plats, however, the undesirable grasses were largely replaced by Kentucky bluegrass and white clover. Moreover the weeds were largely yarrow and buckhorn plantain as compared with yarrow, cinquefoil, antennaria, and buckhorn plantain on the untreated plats. Nitrogen fertilizers tended to increase the percentage of Kentucky bluegrass and to decrease the percentage of white clover. At Moorefield, on the other hand, there was a very good sod of Kentucky bluegrass, and consequently lime and fertilizers had relatively little effect on the botanical composition except in 1933, when there was a large amount of white clover even on the untreated plats. During that year both superphosphate and lime increased the percentage of white clover, whereas nitrogen fertilizers, especially when used in large amounts, caused a very marked reduction in the percentage of clover.

PHOSPHORUS

The phosphorus content of the herbage from the various plats at Morgantown and at Moorefield is shown in Table 3. The herbage (largely weeds and poverty grass) from the untreated plats on the unproductive soil at Morgantown was only 60% as high in phosphorus as the herbage from the untreated plat of the productive soil at Moorefield. The use of liberal applications of superphosphate increased the phosphorus content of the herbage to about the same level on the two areas.

As shown in Table 2 the P–K–L and the 2N–P–K–L plats at Morgantown received the last application of superphosphate in 1932. During the subsequent years the herbage from these plats showed a progressive decrease both in actual phosphorus content and in the relative phosphorus content, based on 100 for the unfertilized plat. The herbage from the plats that received the 2P treatment showed a gradual decrease in phosphorus content after the last application of superphosphate, but the percentage increases over the untreated plats were almost constant. The marked decrease in the phosphorus content of the herbage from all plats in 1935 and 1936 may have been due partly to the unfavorable years. The 1936 season was especially dry, a condition that many other investigators have found to be associated with a low content of phosphorus in the herbage. There were also periods of dry weather during parts of 1931, 1932, and 1933, but

TABLE 3.—*Phosphorus content of the dry herbage clipped from certain of the pasture plats at Morgantown and Moorefield, West Virginia, 1931–36.*

Year	Percentage of phosphorus in herbage				Relative amounts of phosphorus in herbage			
	No treatment	P-K-L	2N-P-K-L	2N-2P-K-L	No treatment	P-K-L	2N-P-K-L	2N-2P-K-L
				Morgantown				
1931	0.179	0.276	0.271	—	100	154	151	—
1932	0.177	0.342	0.346	0.378	100	193	195	214
1933	0.186	0.324	0.309	0.383	100	174	166	206
1935	0.158	0.245	0.216	0.315	100	155	137	199
1936	0.140	0.201	0.174	0.271	100	144	124	194
Av.	0.168	0.278	0.263	0.337	100	165	157	201
				Moorefield				
1931	0.274	0.319	0.309	0.362	100	116	113	132
1932	0.252	0.319	0.331	0.331	100	127	131	131
1933	0.321	0.393	0.369	0.406	100	122	115	126
1935	0.273	0.315	0.313	0.343	100	115	115	126
Av.	0.280	0.337	0.331	0.361	100	120	118	129

in these years most of the herbage was produced during periods when moisture was reasonably plentiful.

At Moorefield the phosphorus content of the herbage from any one treatment was surprisingly uniform for 1931, 1932, and 1935, but was much higher in 1933 The high phosphorus content in 1933 cannot be attributed to the higher percentage of clover, since as shown later in Table 7, clover samples from these plats are lower in phosphorus than bluegrass samples. Moreover, the higher values for 1933 were also very apparent on the plats that received heavy applications of nitrogen fertilizer and consequently contained but little clover. The rainfall, however, was unusually abundant in 1933 and this may account for the high percentage of phosphorus in the herbage.

As would be expected, both the actual and the percentage increases in the phosphorus content of the herbage as a result of phosphorus fertilization were greater on the poor soil at Morgantown than on the fertile soil at Moorefield. The average increases from the P-K-L treatment were 65% at Morgantown and 20% at Moorefield. It is of interest to compare these increases with those found by other investigators. Barnes (5) reported increases of 22 to 64% in the hay and aftermath of three poor pastures that were reseeded and fertilized with 400 pounds per acre of 16% superphosphate. In one pasture no increase was obtained. As on the Morgantown plats, there was a marked change in botanical composition as a result of fertilization and this difference may partly account for the increases in the phosphorus content of the herbage. Blair and Prince (6) obtained an increase of 32% from plats fertilized with 600 pounds of superphosphate. Again there was a marked change in the pasture vegetation.

Brown (7) reported that the use of 1,000 pounds of 16% superphosphate during the previous 6 years increased the phosphorus content of the herbage by about 67% and at the same time resulted in a marked increase in the percentage of Kentucky bluegrass and white clover. Lush (25) obtained increases of 19 to 52% in three different areas. Mortimer and Algren (28) reported an increase of 34% from the use of 1,000 pounds of superphosphate in the previous 3 years on an irrigated Kentucky bluegrass sod. On the other hand, LaMaster (24), Archibald, Nelson, and Bennett (1), and Woodman and Underwood (38) found that phosphorus fertilization had no significant effect on the phosphorus content of the herbage. In at least two of these experiments, however, there was a high percentage of desirable pasture species on the untreated plats and the herbage from these plats was relatively high in phosphorus.

Nitrate of soda resulted in a reduction in the phosphorus content of the herbage at Morgantown, but had no significant effect at Moorefield. Fagan (12), working with pure species, found that, in general, nitrogen fertilizers decreased the total phosphorus content of the grasses. Vinall and Wilkins (37), however, found that nitrate of soda had no significant effect on the phosphorus content of either Kentucky bluegrass or white clover.

Seasonal variations in the phosphorus content of the herbage from certain plat treatments at Morgantown and at Moorefield are given in Table 4. At Morgantown the phosphorus content of the herbage tended to be high in early spring and again in July and August but low in June and September. These differences, however, may be due to seasonal variations in the amounts of bluegrass, white clover, and the various species of weeds and native grasses in the herbage. Thus, on the fertilized and limed plats the first clipping in the spring contains relatively more Kentucky bluegrass but less poverty grass than the second clipping. It is also of interest to note that in 1933 the phosphorus content of the herbage from the 2N-2P-K-L plat, which had received 500 pounds per acre of superphosphate for the years 1930 to 1933, inclusive, was almost constant throughout the season.

At Moorefield the phosphorus content of the herbage in 1931 tended to be low during the dry period in June and early July, with maximum values in August and September. In 1933, a season with unusually abundant and well-distributed rainfall, there was a definite trend toward a high phosphorus content in June and again in August and early September. The periods of low phosphorus content were early spring, July, and late fall. The reasons for these fluctuations are not known.

CALCIUM

The calcium content of the herbage from the various plats at Morgantown and at Moorefield is shown in Table 5. It is interesting to note that the herbage consisting almost entirely of weeds, poverty grass, and broomsedge that was produced on the untreated plats at Morgantown averaged almost twice as high in percentage calcium as that produced during 1931 at Moorefield when the herbage was

TABLE 4.—*Seasonal variations in the phosphorus content of the dry herbage clipped from certain of the pasture plats at Morgantown and Moorefield, West Virginia.*

Year	Date of clipping	Percentage of phosphorus in clipped herbage			
		No treatment	P-K-L	2N-P-K-L	2N-2P-K-L
		Morgantown			
1933	May 15	0.230	0.346	0.328	0.398
	June 7	0.185	0.310	0.309	0.384
	June 29*	0.182	0.315	0.247	0.384
	July 21	0.183	0.327	0.324	0.386
	Aug. 18	0.181	0.340	0.320	0.363
	Oct. 13	0.145	0.316	0.284	0.382
	Weighed average	0.186	0.324	0.308	0.384
1935	May 11	0.201	0.255	0.236	0.320
	June 10*	0.158	0.232	0.202	0.286
	July 10	0.152	0.262	0.216	0.323
	Aug. 23	0.149	0.268	0.224	0.357
	Sept. 10	0.129	0.214	0.203	0.301
	Weighed average	0.158	0.245	0.216	0.315
		Moorefield			
1931	Apr. 29	0.256	0.294	0.319	0.394
	May 29	0.269	0.306	0.304	0.351
	July 9*	0.234	0.274	0.223	0.251
	Sept. 4	0.304	0.360	0.350	0.399
	Oct. 10	0.309	0.379	0.307	0.351
	Weighed average	0.274	0.319	0.309	0.362
1933	Apr. 29	0.274	0.326	0.346	0.408
	May 23	0.303	0.338	0.316	0.355
	June 13	0.350	0.448	0.400	0.424
	July 6*	0.334	0.394	0.408	0.459
	July 29	0.312	0.387	0.367	0.401
	Aug. 21	0.348	0.446	0.416	0.450
	Sept. 12	0.356	0.449	0.460	0.472
	Oct. 24	0.282	0.367	0.390	0.409
	Weighed average	0.321	0.393	0.369	0.406

*The midsummer applications of nitrogen were made at these dates, after the herbage was clipped.

largely Kentucky bluegrass. The high percentage of calcium in the herbage from the untreated plats at Morgantown must be due to weeds, because the calcium content is much higher than that shown in Tables 10 and 11 for the various species of grasses. This assumption is in agreement with the data of Harper, *et al.* (17) who reported that, in general, weeds are higher in calcium, phosphorus, and nitrogen than are grasses.

The increases in the calcium content of the herbage as a result of lime and fertilizer treatments were smaller at Morgantown in 1931 than during subsequent years, presumably because the differences in

TABLE 5.—*Calcium content of the dry herbage clipped from certain of the pasture plats at Morgantown and Moorefield, West Virginia, 1931–36.*

Year	Percentage of calcium in herbage				Relative amount of calcium in herbage			
	No treatment	P-K-L	2N P-K-L	2N-2P-K-L	No treatment	P-K-L	2N-P-K-L	2N-2P-K-L
				Morgantown				
1931	0.77	0.92	0.85	—	100	119	110	—
1932	0.66	1.15	1.10	1.12	100	174	167	170
1933	0.76	1.17	1.04	1.06	100	154	137	139
1935	0.65	0.92	0.86	0.92	100	142	132	142
1936	0.49	0.79	0.74	0.80	100	161	151	163
Av.	0.67	0.99	0.92	0.98	100	148	137	146
				Moorefield				
1931	0.37	0.39	0.37	0.40	100	105	100	108
1932	0.48	0.62	0.43	0.49	100	129	90	102
1933	0.73	1.08	0.58	0.66	100	148	79	90
1935	0.74	0.74	0.65	0.66	100	100	88	89
Av.	0.58	0.71	0.51	0.55	100	122	88	95

botanical composition were still comparatively small. During the 5-year period the P–K–L treatment increased the calcium content of the herbage an average of 48% as compared with 37% for the 2N–P–K–L treatment. This decrease in calcium content resulting from the nitrogen fertilizer undoubtedly was due partly to the reduction in the amount of clover in the herbage. Moreover, the work of Vinall and Wilkins (37), Fagan (12), and Askew (4) shows that nitrogen fertilizers tend to decrease the calcium content of various pasture species. The second increment of superphosphate (2N–2P–K–L compared with 2N–P–K–L) produced a small increase in the calcium content of the herbage, probably due partly to a small increase in the percentage of clover and partly to the calcium supplied by the superphosphate.

The calcium content of the herbage from the Kentucky bluegrass area at Moorefield was closely related to the amount of white clover on the plats. Since nitrogen fertilizer produced a marked decrease in the percentage of clover, the nitrogen treatment resulted in a marked decrease in the calcium content of the herbage during 1933 when clover was abundant. Thus the herbage from the 2N–P–K–L plats averaged only 0.58% calcium as compared with 1.08% for the P–K–L treatment. In 1932 and 1935, when there was relatively little clover on the area, the herbage from the 2N–P–K–L and the P–K–L plats averaged 0.54 and 0.68%, respectively. The relatively high percentage of calcium in the herbage from the untreated plats in 1935 presumably was due to a rather high percentage of buckhorn plantain. During 1931, when the vegetation was largely Kentucky bluegrass, there was relatively little difference between the calcium content of the herbage from the various plats.

Table 6 shows some seasonal variations in the calcium content of the herbage at both Morgantown and Moorefield. During 1933 at Morgantown the calcium content of the herbage from the limed and fertilized plats increased very markedly as the season advanced. This increase was associated with a corresponding increase in the percentage of white clover. On the untreated plats there was a slight, gradual increase until the last cutting, when there was a very marked decrease. Presumably this marked decrease was due to the relatively high percentage of broomsedge in the herbage of the last clipping.

TABLE 6.—*Seasonal variations in the calcium content of the dry herbage clipped from certain of the pasture plats at Morgantown and Moorefield, West Virginia.*

Year	Date of clipping	Percentage of calcium in clipped herbage			
		No treatment	P-K-L	2N-P-K-L	2N-2P-K-L
		Morgantown			
1933	May 15	0.68	0.87	0.83	0.79
	June 7	0.76	0.99	0.99	0.99
	June 29*	0.80	1.07	0.99	1.07
	July 21	0.81	1.21	1.01	1.02
	Aug. 18	0.87	1.24	1.05	1.06
	Oct. 13	0.59	1.54	1.31	1.43
	Weighed average	0.76	1.17	1.04	1.06
1935	May 11	0.65	0.91	0.77	0.78
	June 10*	0.59	0.79	0.83	0.89
	July 10	0.69	1.07	0.95	1.03
	Aug 23	0.73	1.05	0.92	1.00
	Sept. 10	0.77	1.11	0.99	1.00
	Weighed average	0.65	0.92	0.86	0.92
		Moorefield			
1931	Apr. 29	0.39	0.39	0.40	0.44
	May 29	0.31	0.31	0.30	0.32
	July 9*	0.37	0.43	0.40	0.45
	Sept. 4	0.38	0.41	0.39	0.40
	Oct. 10	0.40	0.45	0.44	0.44
	Weighed average	0.37	0.39	0.37	0.40
1933	Apr. 29	0.46	0.55	0.35	0.39
	May 23	0.55	0.82	0.30	0.33
	June 13	0.77	1.16	0.49	0.57
	July 6*	0.89	1.21	0.69	0.80
	July 29	0.95	1.35	0.75	0.83
	Aug. 21	0.82	1.18	0.75	0.83
	Sept. 12	0.62	1.06	0.75	0.83
	Oct. 24	1.04	1.33	1.20	1.31
	Weighed average	0.73	1.08	0.58	0.66

*The midsummer applications of nitrogen were made at these dates, after the herbage was clipped.

During 1935, when there was but little clover on the area, there was only a small increase in the calcium content of the herbage as the season advanced. These seasonal differences may be due to variations in the proportion of grass and various weeds in the herbage, because there was no seasonal trend during 1931 at Moorefield when the vegetation was largely Kentucky bluegrass. The relatively low calcium content of the second clipping at Moorefield in 1931 may have been due to the more mature stage of the bluegrass, because it was in head at that time. As in the Morgantown plats, the variations in the calcium content of the herbage at Moorefield during 1933 appear to be closely related to the proportion of white clover in the herbage. The actual percentage of calcium ranges from 0.30 for the second cutting of the 2N-P-K-L plats to 1.35 for the fifth cutting of the P-K-L plats. The corresponding values for the estimated percentages of white clover on the plats were 2 and 32, respectively.

COMPARISON OF INDIVIDUAL SPECIES GROWN IN ASSOCIATION

PHOSPHORUS CONTENT OF DIFFERENT SPECIES

The phosphorus content of samples of Kentucky bluegrass and of white clover taken from certain of the pasture plats in 1931 and 1933 are given in Table 7. It is of interest first to compare the phosphorus content of the two species. Of the 10 pairs of comparable samples,

TABLE 7.—*The phosphorus content of Kentucky bluegrass and white clover grown in association on untreated and treated pasture plats, miscellaneous samples, 1931 and 1933.*

Experimental plats	Date sampled	Treatment of plats*	Percentage phosphorus		Percentage increase in phosphorus	
			Kentucky bluegrass	White clover	Kentucky bluegrass	White clover
Maidsville	Aug 17, 1931	None	0.248	0.248	—	—
Morgantown	July 16, 1931	None	0.193	0.265†		—
		N-P-K-L	0.274	—	42	—
		N-2P-K-L	0.325	0.305†	68	15
	Oct 12, 1933	P	0.325	0.293		-
		P-L	0.363	0.287		-
		N-P-K-L	0.284	0.245		-
Moorefield	Oct. 24, 1933	None	0.326	0.303	--	--
		P	0.392	—	---	-
		P-L	0.426	0.322	31	6
		P-K-L	0.408	0.321	25	6
		N-2P-K-L	0.437	0.339	34	12
Average (corresponding samples only)			0.333	0.293	40	10

*The last nitrogen application previous to sampling was on March 27 for the 1931 Morgantown plats, June 29 for the 1933 Morgantown plats, and June 6 for the 1933 Moorefield plats. The dates of last clipping previous to sampling were on June 17 to 18, August 18, and September 12, respectively.

†Partly in bloom; all other samples in vegetative, leafy stage of growth.

white clover is higher in phosphorus than bluegrass in only one comparison, the "no treatment" plat at Morgantown in 1931. In the other "no treatment" plats the difference in the phosphorus content of bluegrass and clover is not large. Wherever phosphorus has been applied, bluegrass is considerably higher in phosphorus than white clover. The latter results are not in agreement with results obtained by other investigators (3, 7, 37) who found higher phosphorus values for white clover than for bluegrass. (See first part of Table 14.) These differences might be due to various factors. The samples analyzed in this study were plucked by hand and included most of the stem of the white clover plants. Other investigators, especially those who obtained their samples from pure stands of the species by means of a lawn mower (3, 37), may have had a higher proportion of leaves to stems in their white clover samples. Moreover, the data of Archibald and Bennett (3) are for white Dutch clover, and it is possible that different strains of white clover differ in their phosphorus content.

The phosphorus content of the bluegrass from the untreated plats at Morgantown and Maidsville is considerably lower than that from the untreated plats at Moorefield. Likewise, the white clover from the untreated Maidsville plats is lower in phosphorus than that from the untreated Moorefield plats. These differences are no doubt explained by the higher content of available soil phosphorus in the Moorefield plats (Table 1).

In all cases phosphorus fertilization increased the percentage phosphorus in these species. As shown in the last two columns of Table 7, however, the percentage increase is much greater with bluegrass than with white clover, averaging 40% for the former and only 10% for the latter. Vinall and Wilkins (37) found an increase from phosphorus fertilization of 25.6% in the phosphorus content of bluegrass and of 22.2% in that of white clover, when these species were grown in pure stands.

In Table 8 are given the data obtained from samples of Kentucky bluegrass, broomsedge, and poverty grass taken from some of the Morgantown plats in the late summer of 1936, 4½ years after the last fertilization with phosphate. The phosphorus content of these samples of bluegrass is lower than of samples taken from the same plats in 1931. This is no doubt partly due to seasonal variations. It is significant, however, that the samples from the "no treatment" plats are only 19% lower than in 1931, whereas the N-2P-K-L and N-P-K-L samples are 26 and 30% lower, respectively. This indicates, as did the analysis of the mixed herbage (Table 5), that the available phosphorus content of the treated plats is gradually decreasing.

The phosphorus content of Kentucky bluegrass is considerably higher than that of broomsedge and poverty grass grown in association with it. The difference is particularly marked between bluegrass and poverty grass grown on the unphosphated plats. Phosphorus fertilization has materially increased the phosphorus content of all three species. As shown in the last three columns of Table 8, the average percentage increase is approximately twice as large from the "high P" treatments as from the "moderate P" treatments. Of particular interest, too, is the fact that the average increase is

about twice as high for poverty grass as for broomsedge and bluegrass. This means that, while bluegrass is 60% higher in phosphorus than is poverty grass on the untreated plats, it is only 14% higher on the heavily phosphated plats.

TABLE 8.—*The phosphorus content of different species grown in association on untreated and treated pasture plats, Morgantown Experiment, samples collected September 11 to 16, 1936.*

Plat treatment*	Phosphorus content, %			Percentage increase in phosphorus†		
	Kentucky bluegrass	Broomsedge	Poverty grass	Kentucky bluegrass	Broomsedge	Poverty grass
None	0.162	0.129	0.100	--	—	--
L	0.160	0.123	0.109	—	—	
P	0.241	0.170	0.214	49	32	114
P-L and P-K-L	0.249	0.163	0.192	54	26	92
N-P-K	0.197	0.192	0.188	22	49	88
N-P-K-L	0.211	0.171	0.178	32	39	63
N-2P-K-L	0.257	0.220	0.243	59	70	143
K-L-Ammo-phos	0.340	0.231	0.283	110	79	183
Average:						
"No P" plats	0.161	0.126	0.105	—	--	—
"Moderate P" plats	0.223	0.173	0.186	39	37	79
"High P" plats	0.299	0.226	0.263	85	75	163

*The dates of last nitrogen application and of last clipping previous to sampling were June 12 and August 4, respectively.

†Represents increase over "no treatment" for unlimed plats and increase over "L" for limed plats.

When fertilizers containing phosphorus have been applied, there is an indication that lime has increased slightly the phosphorus content of bluegrass, but that it has decreased the phosphorus content of broomsedge and poverty grass. This is possibly explained by the difference in competition between bluegrass and the other species on the different plats. On the unlimed plats bluegrass is found only in small amounts, whereas on the limed plats it composes about 40 to 50% of the vegetation and probably competes successfully with the poorer species, poverty grass and broomsedge, for the available phosphorus of the soil. Moreover, it is probable that the poorer species can feed better than bluegrass on iron and aluminum phosphates present in the unlimed soil.

The addition of nitrogen to the fertilizer has resulted in a decrease in the phosphorus content of bluegrass. This agrees with the data given in Table 7, and also the results obtained by Fagan (12). The explanation for this is not clear, especially since the effect of the nitrogen had been exhausted previous to the growth of the grass which was analyzed. Nitrogen, however, had caused increased yields of grass during the past 7 years and this had no doubt caused a greater removal of phosphorus from the soil than where no nitrogen had been applied.

A summary of the relative phosphorus content of the three species is given in Table 9. Regardless of the phosphate fertilization, broomsedge is only about 70 to 80% as high in phosphorus as is bluegrass.

Poverty grass, on the other hand, is, in general, less than 70% as high in phosphorus as bluegrass where the soil is low in phosphorus, but is 83 to 95% as high where phosphate fertilizers have been used

TABLE 9.—*Relative phosphorus content of Kentucky bluegrass, broomsedge, and poverty grass as affected by phosphate fertilization*

Plat treatment	Location of plats and year sampled	Relative phosphorus content (Kentucky bluegrass = 100)	
		Broomsedge	Poverty grass
	No P		
None	Maidsville, 1931	—	75
None	Morgantown, 1931	—	69
None	Morgantown, 1936	79	62
Lime	Morgantown, 1936	77	68
	Moderate P		
N-P-K-L	Morgantown, 1931		87
All "moderate P" plats	Morgantown, 1936	78	84
	High P		
N-2P-K-L	Morgantown, 1931	—	83
N-2P-K-L	Morgantown, 1936	86	95
K-L-Ammo-phos.	Morgantown, 1936	68	83

CALCIUM CONTENT OF DIFFERENT SPECIES

The calcium content of samples of Kentucky bluegrass, white clover, and poverty grass collected from various plats in 1931 and 1933 is given in Table 10. The percentage of calcium in Kentucky

TABLE 10.—*The calcium content of different species grown in association on untreated and treated pasture plats, miscellaneous samples, 1931 and 1933*

Experimental plats	Date sampled	Plat treatment*	Percentage calcium		
			Kentucky bluegrass	White clover	Poverty grass
Maidsville	Aug. 17, 1931	None	0.362	1.38	0.176
Morgantown	July 16, 1931	None	0.302	1.56*	0.174
		N-P-K	0.371	—	0.164
		N-2P-K-L	0.401	1.53*	0.193
Morgantown	Oct. 12, 1933	P	0.492	1.62	—
		P-L	0.575	1.92	—
		P-K-L	0.498	1.96	—
Moorefield	Oct. 24, 1933	None	0.465	1.43	—
		P	0.555	—	—
		P-L	0.564	1.53	—
		P-K-L	0.484	1.48	—
Average relative values			100	348	49

*See footnotes to Table 7.

bluegrass varies from 0.302 to 0.575, the average for all samples being 0.461. The values for white clover vary from 1.38 to 1.96%, and the average value is approximately 3½ times as high as that for bluegrass. On the other hand, poverty grass is only about 49% as high in calcium as is bluegrass.

The three species also show a difference in the percentage increase in calcium due to fertilization and liming, the percentage increase being less for white clover and poverty grass than for bluegrass. The use of superphosphate or of a complete fertilizer materially increased the calcium content of bluegrass. This is in agreement with the data of Brown (7) and of Vinall and Wilkins (37), and is no doubt accounted for by the calcium content of the superphosphate. The addition of potash to the fertilizer decreased the calcium content of bluegrass but had no consistent effect on that of white clover. The inverse relationship between calcium and potassium in bluegrass is in agreement with the results of Godden (16) and with unpublished data obtained at this laboratory.

Table 11 gives the calcium content of the 1936 samples of bluegrass, broomsedge, and poverty grass. It will be noted that broomsedge has about the same calcium content as poverty grass. These species, however, are only about 70% as high in calcium as bluegrass when grown on the unlimed plats, and only 60 to 65% as high when grown on the limed plats. Fertilizers had about the same effect on the calcium content of the bluegrass as they did in 1931 and 1933. Because of the increased acidity developed from ammonium sulfate and Ammo-phos, however, the samples of bluegrass taken from these plats unlimed were lower in calcium than were those taken from the plats which received nitrate of soda as the source of nitrogen.

TABLE 11.—*The calcium content of different species grown in association as affected by lime and fertilizer treatments, Morgantown plats, sampled September 11 to 16, 1936.*

Treatment*	Kentucky bluegrass		Broomsedge		Poverty grass	
	Unlimed plats, %	Limed plats, %	Unlimed plats, %	Limed plats, %	Unlimed plats, %	Limed plats, %
None	0.376	0.545	0.263	0.318	0.255	0.318
P	0.452	0.545	0.279	0.294	0.297	0.368
N-P-K	0.416	0.518	0.315	0.314	0.267	0.363
N-P-K-$(NH_4)_2SO_4$	0.337	0.481	0.260	0.367	0.294	0.335
K-Ammo-phos	0.390	0.588	0.286	0.379	0.272	0.348
Average	0.394	0.535	0.281	0.334	0.277	0.346
Average relative values	100	100	71	62	70	65
Average increase from liming (%)	35.8		18.9		24.9	

*See first footnote to Table 8.

The percentage increase in calcium content as a result of liming was considerably higher with bluegrass than with broomsedge and poverty grass, the values being 35.8, 18.9 and 24.9, respectively.

ACID-BASE BALANCE OF DIFFERENT SPECIES

Of interest in connection with the calcium and phosphorus content of these pasture species is their acid-base balance. Studies were made of the acid-base balance of a few samples according to a slight modification of Frear's method (15). The results are given in Table 12. The term "excess base" refers to the amount of bases in the sample in excess of that necessary to combine with phosphorus, chlorine, and sulfur. The differences in the "excess base" among the different grass species are fairly closely related to the differences in the calcium content given in the preceding tables. On the other hand, white clover is approximately 3.8 times as high in calcium as is bluegrass but is only 2.9 times as high in "excess base". Likewise, white clover is 7.9 times as high in calcium as is poverty grass, but 5.1 times as high in "excess base". This difference is at least partly due to differences in the relative percentage of calcium to other bases in the grasses and clovers. Thus, in the samples of pure species analyzed by Brown, white clover was only 70% higher in potassium than in calcium, whereas the potassium content of Kentucky bluegrass, sweet vernal grass, and Rhode Island bent exceeded the calcium content by 355, 291, and 359%, respectively.

TABLE 12.—*The "excess base" of different species grown in association.*

Treatment	Source of sample	Milligram equivalents per 100 grams			
		White clover	Kentucky bluegrass	Broomsedge	Poverty grass
N-P-K	Morgantown, 1936	—	44.6	32.4	29.0
N-2P-K-L	Morgantown, 1936	—	45.9	29.3	32.6
None	Maidsville, 1931	126.6	46.4	—	25.5
N-2P-K-L	Morgantown, 1931	147.0	48.4	—	27.8
Average		136.8	46.3	30.9	28.7

NITROGEN CONTENT OF DIFFERENT SPECIES

The nitrogen content of Kentucky bluegrass, broomsedge, and poverty grass growing in association on some of the plats is given in Table 13. In considering these data it should be remembered that the nitrogen application had been made approximately 3½ months previously and that the effect of nitrogen on growth at the time the samples were taken had largely disappeared. For comparative purposes the relative values based on Kentucky bluegrass as 100 are shown in the last two columns of the table. These values show a uniformly lower content of nitrogen for broomsedge and poverty grass than for bluegrass. Broomsedge averages 76% as high in nitrogen as bluegrass and poverty grass averages 74% as high.

GENERAL DISCUSSION

It is of interest to consider briefly the calcium and phosphorus contents of the herbage and of the individual species obtained in this in-

TABLE 13.—*Nitrogen content of different species grown in association.*

Treatment*	Percentage nitrogen			Relative values (Kentucky bluegrass = 100)	
	Kentucky bluegrass	Broom-sedge	Poverty grass	Broom-sedge	Poverty grass
		Maidsville, 1931			
None	2.76	—	1.62	—	59
		Morgantown, 1931			
None	2.07	—	1.53	—	74
N-2P-K-L	2.33	—	1.49	—	64
		Morgantown, 1936			
None	2.12	1.56	1.47	74	69
P-L and P-K-L plats	2.21	1.67	1.68	76	76
N-P-K-L and N-2P-K-L plats	2.39	1.85	1.83	77	77
Average (Morgantown, 1936)	2.24	1.69	1.66	76	74

*See footnotes to Tables 7 and 8

vestigation in relation to the mineral requirements of the grazing animal. Archibald and Bennett (2) concluded, after a review of the literature, that 0.15% of phosphorus in the herbage is the lower limit of safety, below which point the deficiency may seriously lower the value of the pasture for grazing purposes. The type of animal will of course influence the minimum requirements of phosphorus and calcium in the vegetation. Thus, Henderson and Weakley (20) found that for growing dairy animals "rations which contain less than 0.35% of calcium or less than 0.20% of phosphorus give rise to a bone which is low in ash and consequently low in calcium and phosphorus, but high in moisture and extractable material". Moreover, Huffman and co-workers (22) found that for high-producing dairy cows even 0.20% phosphorus in the ration is inadequate.

On the basis of a requirement of 0.20% phosphorus, it is evident that the untreated Morgantown pasture, which, as previously mentioned, contains mostly poverty grass, weeds, and broomsedge and is representative of a large acreage of untreated pastures in the state, produced herbage definitely inadequate in phosphorus. The average percentage phosphorus over the 5-year period was 0.168. One clipping contained 0.129% phosphorus, and the average value for the relatively dry year of 1936 was only 0.140%. On the other hand, the herbage of the Moorefield pasture, which contained mostly Kentucky bluegrass, averaged 0.28% phosphorus for the 4 years, and the lowest value of any of the clippings was 0.234%. These data, together with those obtained from an analysis of the individual species, lead to the conclusion that, in general, pastures containing a high percentage of Kentucky bluegrass or a combination of bluegrass and white clover will contain an adequate amount of phosphorus in the young herbage.

It is true that the Kentucky bluegrass from the untreated Morgantown plats contained only 0.160 to 0.193% phosphorus, but these plants were barely able to survive and made up only 3 to 10% of the plant population. Wherever conditions existed which enabled bluegrass and clover to crowd out poverty grass and other undesirable species, the phosphorus content of the bluegrass and of the total herbage was well above 0.20%. Poverty grass and broomsedge, however, contained as low as 0.100 and 0.129% phosphorus, respectively, on the untreated Morgantown plats where they constituted the main part of the vegetation. The result of phosphorus fertilization was to increase the phosphorus content of these species, but under such treatment they were no longer the dominant species in the vegetation.

As regards calcium, it appears that the herbage of West Virginia pastures contains an adequate amount, if a value of 0.35% is considered sufficient. Even the poor, untreated plats of the Morgantown pasture contained an average of 0.67% calcium, a higher value than for the herbage from the untreated plats at Moorefield. The high value is no doubt due to weeds, for as shown in the analysis of the individual species, samples of poverty grass from the untreated Morgantown plats contained only 0.174 to 0.255% calcium, and samples of broomsedge averaged 0.263%. In broomsedge and poverty grass pastures that contain only a small percentage of edible weeds, therefore, calcium may be deficient in the herbage.

Another question of considerable practical as well as theoretical importance as regards the calcium and phosphorus content of important pasture species is the relation between the percentage content in the plant and the sufficiency of the element for optimum growth. Macy (26) has recently presented an interesting theory regarding the value of such a relationship in obtaining a quantitative measure of the mineral nutrient requirement of plants. Every plant species is believed to have a *critical percentage* of each nutrient, which value represents the minimum at which optimum yields are obtained. Above the critical percentage there is *luxury consumption* and between the critical percentage and the *minimum percentage, poverty adjustment*. Unfortunately, neither the data obtained in this investigation nor those reported in the literature regarding pasture species are sufficiently comprehensive for a detailed study of Macy's theory. It is of interest, however, to compare briefly the calcium and phosphorus contents of Kentucky bluegrass and white clover as found by different investigators. These are given in Table 14. It should first be noted that the minimum value of 0.16% phosphorus found for Kentucky bluegrass in this investigation agrees quite closely with the value of 0.17% obtained by Brown (7). Likewise, Cooper and Wilson (9) and Forbes, *et al.* (14) have reported minimum values of 0.18 and 0.17% of phosphorus, respectively, for bluegrass.

The *critical percentage* of phosphorus can be determined only where yield data are available for plats receiving different increments of phosphorus fertilizers. As previously mentioned there was a good sod of Kentucky bluegrass on the Moorefield pasture at the time the experiment was started in 1930. Since white clover did not appear on the experimental area until rather late in the 1932 season, the herbage

TABLE 14.—*The phosphorus and calcium content of Kentucky bluegrass and of white clover as found by different investigators.*

Investigators	Kentucky bluegrass		White clover	
	Range	Average*	Range	Average*
		Percentage Phosphorus		
Archibald and Bennett, Mass †	—	0.38	—	0.45
Brown, Conn. .	0.18–0.31	0.31	0.34–0.41	0.37
Vinall and Wilkins, Wash., D. C	0.39–0.49	0.49	0.45–0.55	0.55
Authors, W. Va	0.16–0.44	0.37‡	0.24–0.34	0.30‡
		Percentage Calcium†		
Archibald and Bennett, Mass	—	0.40	—	1.61
Brown, Conn	0.34–0.55	0.43	1.15–1.57	1.38
Vinall and Wilkins, Wash., D. C.	0.48–0.54	0.49	1.25–1.41	1.34
Authors, W. Va . .	0.30–0.59	0.50	1.38–1.96	1.68

*Average values for phosphorus are for phosphated plats only, and average values for calcium for all limed plats

†No phosphate or lime applied at time plats were started, but surface soil was high in available phosphorus (154 p p m , Truog method) and had a pH of 6 05

‡Represents the average of all plats from which samples of both Kentucky bluegrass and white clover were taken

was almost pure Kentucky bluegrass during 1930, 1931, and the early part of 1932. During this period there was a highly significant increase in yield from the normal application of phosphorus, but no additional increase was obtained from the double phosphorus application. Since, according to Table 3, the average phosphorus content of the herbage in 1931 averages 0.274, 0.313, and 0.362%, respectively, for the no phosphorus, normal phosphorus, and double phosphorus treatments, it follows that 0.274% is below the *critical percentage* and that 0.313 is probably above it. Assuming 0.30 to be the *critical percentage*, the values of 0.16 to 0 30% represent, according to Macy, *poverty adjustment* or the range where phosphate fertilization would increase both the yield and the phosphorus content of the plant. Values above 0.30% would then represent luxury consumption. Although this value can be considered only tentative, it is interesting to note (Table 14) that it indicates a luxury consumption of phosphorus in the samples of bluegrass studied by Archibald and Bennett (3) and Vinall and Wilkins (37). That Archibald and Bennett's values represent luxury consumption is corroborated by the fact that their soil contained 154 p. p. m. of readily available phosphorus.

These data suggest the desirability of obtaining more information regarding the critical percentages of various nutrients for different pasture species. As regards calcium and the other bases, the problem is somewhat complicated, as pointed out by Macy, because of the partial replacement of one base for another. The data summarized in Table 14 indicate that the variations in the calcium content of bluegrass are not as great as that of phosphorus. It is also interesting to note that the average calcium content of bluegrass grown on limed soil, as found by the different investigators, is quite similar.

SUMMARY

Calcium and phosphorus, and in some cases total nitrogen and "excess base", were determined on samples of pasture herbage and of pure species of Kentucky bluegrass, white clover, poverty grass, and broomsedge collected during the period of 1931 to 1936. The samples were obtained from variously fertilized and limed plats on two different soils.

The herbage from the unproductive soil at Morgantown was only 60% as high in phosphorus as the herbage from the untreated plats of the fertile soil at Moorefield. Liberal fertilization increased the phosphorus content of the herbage to about the same level on the two areas. The percentage increases, however, were 29 at Moorefield and 101 at Morgantown.

The calcium content of a mixed herbage is apparently determined largely by the botanical composition of the pasture, which in turn is related to the lime and fertilizer treatments White clover and some of the common weeds are much higher in percentage of calcium than are the grasses.

When grown in association on a number of untreated and of variously treated plats, white clover was found to average 88% as high in phosphorus as bluegrass, but 248% higher in calcium. Phosphorus fertilization increased the phosphorus content of white clover an average of 10% as compared with an average of 40% for Kentucky bluegrass.

Broomsedge contained 68 to 86% as much phosphorus and 54 to 76% as much calcium as Kentucky bluegrass. The percentage increase in phosphorus from the use of phosphate fertilizers was approximately the same for broomsedge as for bluegrass. The use of lime on the acid Morgantown plats increased the percentage of calcium in broomsedge by an average of 19 as compared to an average of 36 for bluegrass.

Poverty grass averaged less than 70% as high in phosphorus as bluegrass on the untreated plats, but approximately 85% on plats receiving a high amount of phosphorus fertilizer. The percentage increase in the phosphorus content of poverty grass from phosphate fertilizers was approximately twice as high as that for bluegrass Poverty grass was 49 to 70% as high in calcium as bluegrass and the average increase in the calcium content of poverty grass from liming was 25% as compared to 36% for bluegrass.

The "excess base" content of white clover was 195% higher than of Kentucky bluegrass, whereas broomsedge and poverty grass averaged only 67 and 62% as high as bluegrass, respectively.

Broomsedge and poverty grass averaged 76 and 74% as high in nitrogen, respectively, as did bluegrass

It is concluded from a consideration of the data obtained with both the mixed herbage and the individual species that the herbage from many West Virginia pastures is likely to be insufficient to meet the phosphorus requirements of the grazing animal, but probably contains, in general, a sufficient amount of calcium.

The minimum and average percentages of calcium and phosphorus for Kentucky bluegrass and white clover obtained in this study are

compared with the values obtained by other investigators, and the phosphorus content of bluegrass discussed in relation to Macy's theory. The data indicate that the *minimum percentage* of phosphorus for bluegrass in the vegetative stage of growth is approximately 0.16% and the *critical percentage* approximately 0.30%.

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MODIFICATION OF CHEMICAL COMPOSITION OF PASTURE PLANTS BY SOILS[1]

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THE effect of soils on the chemical composition of plants may be studied by analyzing them, or indirectly, by noting malnutrition disorders of grazing animals in certain soil areas. A brief resumé of some of the available information on these subjects forms the basis of this paper. The effect of added fertilizers on the chemical composition of pasture plants is presented elsewhere in this symposium (pages 477 to 497).

It has long been known that plants are materially affected by the nature of the soil in which they grow. As early as 1869, Hellriegel (15)[3] found that their nitrogen and mineral composition varied with that of the soil. Considerable data are available which show that crops grown on different soil types vary not only with respect to yield, but also with respect to quality, palatability, color, nutritive value, and chemical composition. Soil physical and chemical characteristics affect both plant nutrient availability and moisture availability, the latter being an extremely important matter during drouthy periods Hence, it is that soil type not only modifies the chemical composition of individual plants but also the botanical character of the vegetation which has an important bearing upon herbage composition.

Soil texture largely determines the availability of moisture and plant nutrients. A fine-textured soil usually has a high colloid content. Since colloids have a tremendous surface area compared with sands, and since the reaction of solids and liquids is proportional to area of contact, it is evident that soil texture is very important It has been estimated that were it possible to subdivide coarse sand into particles the size of the finest clay or colloids, its surface exposure would be increased from 10,000 to 1,000,000 times. In such an event, it is fair to assume that its chemical and physical properties would be similarly augmented. For this reason Scarseth (23) claims that fertilizers, especially phosphates, should be applied on the basis of soil colloid content rather than on an acre basis. He further states that an application of 2,000 pounds of superphosphate to a soil with a 60% colloid content is equivalent to one of 300 pounds on a soil with 9% colloids.

It is evident, therefore, that fine-textured soils have a greater capacity than sandier soils for absorbing and holding plant nutrients as well as water. This is clearly shown by the work of Walker and Brown (27) who found that the total phosphorus, nitrogen, and carbon increased as texture in the Carrington series changed from sand to silt loam. Unfertilized fine-textured soils usually produce herbage higher in ash and digestible nutrients than coarse-textured soils. Archibald and Bennett (1) found that loams and sandy loams with

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[2]Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 502.

rather compact substratum had good water-holding capacities and produced herbage higher in protein and calcium and correspondingly lower in fiber than the sandy loams.

Midgley and Weiser (19) found that the potash content of timothy grown on untreated soils correlated with the available potash in the soil. The fine-textured clay soils in the Champlain Valley contained much more total and available potash than the coarser-textured sandy loams, and this was reflected in plant composition.

Cooper, *et al.* (5) found a close correlation between the chemical composition of the ash of pasture plants and the available soil constituents. The ash of plants grown on unfertile acid soils often contains relatively large amounts of silica and other hard elements, such as aluminum, manganese, and iron, whereas the ash of plants grown on fertile soils usually contain relatively large amounts of the soft elements, such as phosphorus, potassium, and calcium. It is believed that the presence of the hard elements tends to decrease the palatability of herbage and to make it less desirable.

The chemical composition of pasture herbage as affected by soil in the British Isles is reported by Godden (11) and reproduced in Table 1.

TABLE 1.—*Comparison of hill and lowland pastures from same locality in Great Britain.*

Material	Scotland		Montgomeryshire		Cardiganshire	
	Hill %	Lowland %	Hill %	Lowland %	Hill %	Lowland %
Lime (CaO)	0.152	0.281	0.788	0.947	0.352	1.080
Phosphorus (P_2O_5)	0.420	0.875	0.429	0.869	0.652	0.788
Sodium (Na_2O)	0.115	0.393	Trace	0.037	0.051	0.416
Potash (K_2O)	2.220	3.017	3.062	4.360	3.423	2.988
Chlorine (Cl)	0.644	0.747	1.706	1.078	1.086	1.132
Nitrogen (N)	2.269	3.301	2.189	4.005	2.624	3.374
Total ash	4.267	8.600	7.083	10.551	6.756	10.308
Silica free ash	4.020	6.884	5.490	8.472	5.796	7.288
Crude fiber	25.50	18.30	24.09	17.22	24.71	16.13
Calories per 100 grams	282.2	295.0	273.0	289.0	274.0	294.0

Clearly the lowland soils produced herbage with a higher mineral and a lower fiber content than the highland soils.

In regard to the rarer elements, Young (29) cites references indicating that the greatest quantities of iodine occurred in soils derived from limestone strata and the least in soils derived from sandstone; that more manganese was found in clay and clay loams than in sandy and sandy loams; that magnesium was most deficient on acid soils or where potash had been freely used as a fertilizer; and that muck and peat soils are quite often deficient in copper. Since soils vary thus in their content of rare elements, it is possible that plants composition may vary accordingly.

Soil type has a marked effect on the kind of vegetation produced. Prince, *et al.* (20) found that clover pastures were generally located

on the finer-textured soils and concluded that the maintenance of white clover was somewhat dependent on soil texture and moisture content. Since legumes usually contain a higher percentage of minerals and always a higher percentage of protein than grasses, their presence affects the chemical composition of the pasturage. Daniel (8) found that 10 different legumes averaged to contain 3.9 times as much calcium, 1.7 times as much phosphorus, and 2.6 times as much nitrogen as the grasses. He also states that crops which are high in calcium and phosphorus always contain relatively large amounts of these elements even though they are produced on poor soil. This may be due to the inherent feeding capacity of the plant as sundry species seem to differ greatly in chemical composition on any given soil type. The nature of a soil, by influencing botanical composition of the herbage, indirectly affects its chemical composition.

There is considerable indirect evidence which shows that soils affect the chemical composition of pasture plants. It has long been known that cattle will reflect in their performance and physical condition the nutritive value of the pasturage and the fertility of the soil, if long restricted to native forages grown on any particular pasture area. This is why the bluegrass region in Kentucky and parts of the British Isles have become famous for their livestock. There are many other areas, however, where the livestock is less thrifty and productive on ranges where soil and herbage contain an insufficiency of minerals. In such areas, cattle frequently manifest their need of additional minerals by eating oyster shells, wood, leather, etc. It has been established that phosphorus deficiencies exist in Florida (2), Michigan (18), Montana (25, 28), Minnesota (9), Texas (24), Wisconsin (13), Washington (17), and in many foreign countries (16, 21, 26).

Other nutritional disturbances, such as sterility, weak and small calves, loss of weight, "red water", and abnormal appetite, have been ascribed by Holtz (17) to phosphorus deficiency in the home-grown forage fed to cattle in western Washington. When hay has been brought in from irrigated sections, however, these troubles have disappeared. In most of these sections the available phosphorus content of the soil has been low and consequently the phosphorus content of the vegetation has been low. In most cases such soils have responded to phosphatic fertilizers, especially when leguminous plants were grown. In the badly affected areas in Norway, where nutritional disorders occur, Tuff (26) shows that forage crops contain only one-third the normal content of calcium and phosphorus.

An insufficiency of iron and copper in vegetation has been found to cause nutritional anemia. Bryan (3) found many "salt sick" cattle on certain Florida soil types, especially fine sands and peats. On the other hand, range soils, mainly sandy loams or sands with sandy loam or clay subsoils, contained in their surface portions ten times as much iron, twice as much copper, five times as much phosphorus, and five times as much calcium as did soils in the "salt sick" areas.

Most of these nutritional disorders are due to an insufficient supply of one or more minerals in the forage. However, minute amounts of selenium in the soil have caused acute poisoning and prompt death (4), "blind staggers" and "alkali disease" being the local names ap-

plied to this condition. Selenium poisoning is quite common in some far western states where the mean annual rainfall is insufficient to produce percolation through the soil profile. Soils derived from shales of the Cretaceous period are most at fault, sandy soils seldom giving trouble owing to the low content of the parent material and to excessive leaching. The amount of selenium appearing in vegetation varies greatly with the concentration in the soil and its sulfur content, the latter limiting the amount of selenium taken up by plants. It has been established that soils containing 0.5 p.p.m. and vegetation with 5.0 p.p.m. of selenium are potentially dangerous. At Lysite, Wyoming, where several thousand sheep have died from forage poisoning within a few years, shale samples were found containing 22 p.p.m. and *Astragulus* (milk vetch), which sheep relish, containing 4,420 p.p.m. of selenium.

Other nutritional disorders have been noted, such as goiter, due to lack of iodine, located especially in the Great Lakes region, and enameled teeth, due to an excess of fluorine in drinking water, noted especially in Arizona.

Many workers (6, 10, 14) have observed marked seasonal variations in the chemical composition of plants due, in the main, to fluctuations in rainfall and available moisture. Some soils hold water more readily and are less "leachy" than others, and the botanical and chemical composition of the herbage is affected accordingly. Daniel and Harper (7) found that during periods when rainfall was high the calcium content of plants decreased while that of phosphorus increased, whereas the exact reverse situation obtained when the effective rainfall was low. Unpublished work by the writer while at Wisconsin showed that the available phosphorus content of soils was nearly always higher in the early spring than it was in the early fall when the soil was much dryer. This may help explain why plant ash usually contains less phosphorus during a drouthy period, thus affecting the seasonal composition of the vegetation.

SUMMARY

Plants are materially affected by the nature of the soil on which they grow. If the soils are high in available plant nutrients, it will be reflected in the chemical composition of the plants and likewise in the performance and physical condition of the grazing animals.

There are many soil and pasture areas that are known to produce nutritional disorders. Lack of certain minerals, such as calcium and phosphorus, in the herbage are perhaps most common, but insufficiency of iron and copper found on some soil types leads to animal anemia. Goiter is prevalent in areas where iodine content of soils and plants is low. An excess of fluorine may produce teeth disorders. Some soils produce vegetation carrying lethal doses of selenium.

Soil texture has a pronounced effect on the availability of moisture and plant nutrients. Fine-textured soils are better able to store up and hold these materials than the more sandy types, and they usually produce better vegetation higher in minerals and digestible nutrients. Clay loams or fine-textured subsoils containing much colloidal material are better able to withstand drouth than the more open sandy

soils or subsoils. Since available moisture is often a limiting factor in the production of good pasture, it is evident that soil type has a marked effect on the quality and quantity of herbage.

Soil type greatly affects the kind of plant it will support. If sufficient moisture and minerals are present, more clover will be produced than where these essentials are lacking. Since legumes contain more protein and minerals than the grasses, it is evident that soils by influencing the botanical composition indirectly affect the chemical composition of the herbage.

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INTERPRETATION OF VARIATIONS IN PLANT COMPOSITION IN RELATION TO FEEDING VALUE[1]

L. A. Maynard[2]

THE nutritive value of any feed is governed by its content of energy-producing nutrients, that is, its total nutritive energy, and by its content of nutrients specifically essential to the body, namely, protein and certain minerals and vitamins. Forage crops contain all of these nutritive factors, but in highly varying amounts according to species, stage of growth, cultural conditions, and other factors.

ENERGY

While the newer developments of nutrition have dealt particularly with the specific nutrients, it should not be forgotten that the primary rôle of forage crops in animal nutrition is to furnish energy. They provide a cheap source of energy which the herbivorous animal, because of his digestive tract, can utilize effectively but which man cannot, and which are suited to the omnivora to only a very limited extent. The herbivorous-animal industry rests primarily on this fact; for an outlet is thus provided for products which otherwise would be largely agricultural wastes. It is therefore appropriate to give first consideration to the energy value of forage crops as influenced by their composition.

Yield of dry matter is commonly used as an approximate measure of the ability of a given crop or soil to provide total nutritive energy for animals. It should be appreciated that, while there is a close correlation between dry matter and gross energy, several variable factors govern the extent of the utilization of this gross energy by the animal for productive purposes. As an extreme example, alfalfa hay and oat straw have approximately the same gross energy value, yet so much of the energy of the straw is undigested or dissipated as heat in metabolism that this forage has very little value for productive purposes.

The energy supplied by forage crops comes very largely from carbohydrates. This group of nutrients makes up from 60 to 85% of the dry matter, depending primarily upon the stage of growth and the species. The nature of these carbohydrates is the primary factor determining the digestibility of the feed in question and thus of the productive energy content of its dry matter. Since the nature of the carbohydrate present is governed by stage of growth, rate of growth, fertility of the soil, and other cultural factors, a consideration of these relationships becomes important.

For the purposes of this discussion it is convenient to divide the higher carbohydrates into three groups, *viz.*, starch, cellulose, and hemicellulose. As is well understood, starch is readily and nearly completely digested in the animal body. Cellulose, on the other hand, is

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not digested by any enzymes secreted by mammalian tissues but is partially broken down by bacteria in the rumen and to a lesser extent in the large intestine. In this way a portion of its energy becomes utilizable by the animal. Cellulose may occur either as such or combined as a compound cellulose of which ligno-cellulose is of most interest in the present discussion. Lignin is an aromatic compound which is attacked neither by digestive enzymes nor by bacteria. Thus its combination with cellulose represents an inert material which contains no energy available to the animal. Hemicellulose is a rather indefinite term which is here used to include those higher carbohydrates other than starch which are broken down by weak acids and alkalies in contrast to cellulose which is not thus attacked. Hemicellulose includes various pentosans and some hexosans. It is readily broken down by bacterial action but little or no enzymic digestion occurs.

By a rather arbitrary chemical separation the feed chemist divides the higher carbohydrates into crude fiber and nitrogen-free extract. Crude fiber consists almost entirely of cellulose and lignin together with some resistant hemicellulose. Thus its usefulness as a source of energy is dependent entirely on bacterial decomposition. Nitrogen-free extract consists of starch and most of the hemicellulose, but it also may contain some lignin and perhaps some cellulose. Thus the separation has a variable significance as regards digestibility. In some feeds where the nitrogen-free extract is largely starch this extract is much more digestible than the crude fiber fraction, but if the extract consists principally of hemicellulose its digestibility is much less accordingly. Since lignin is entirely unattacked, the higher its proportion in the crude fiber the lower the digestibility of this fraction. These facts are particularly important to bear in mind in connection with forage crops because of the highly variable nature and distribution of the higher carbohydrates in these crops. The effect upon digestibility is a more general one than that represented by the specific carbohydrates involved. Lignin is not only unattacked by bacteria itself, but it hinders the action of the bacteria upon the cellulose with which it is infiltrated. Cellulose which is not broken down by bacterial action in turn hinders the action of the digestive enzymes on the starch, protein, and fat contained in the plant cell.

The rate of growth and stage of maturity are important factors governing the relative amounts of these higher carbohydrates present in a forage crop and thus they are influential in determining its nutritive value. In the young cell wall cellulose exists alone, but with age this cellulose becomes infiltrated with lignin and other encrusting substances. A very small increase in lignin content apparently results in a markedly lower digestibility. Lignification occurs more rapidly as the rate of growth declines either at maturity or earlier when dry weather or some other unfavorable condition retards growth. These facts explain why pasture grass is more easily and more completely digested than hay, why time of harvest is important for hay and silage, and why dry weather which retards active growth lowers nutritive value per unit of dry matter in addition to lessening the total yield. Digestion trials have shown that dried pasture grass has approximately 25% more total digestible nutrients than early cut

hay. They have also shown that early cut hay has 20% more than hay cut in late bloom or in seed. There is considerable evidence that changes in lignin content are primarily concerned in these differences. The inferior nutritive value of pasture where growth is greatly retarded or stopped because of dry or cold weather, in comparison with rapidly growing spring grass, has also been explained on the basis of lignification. Experimental evidence bearing on the above is to be found in the papers of Waentig and Gierisch (15),[3] Rogozinski and Starzewska (13), Woodman and Stewart (17), Newlander and Jones (10), Isaachsen and coworkers (7), Pringsheim (11), Woodman (16), and Prjanishnikow and Tomme (12).

The brief, foregoing discussion should serve to illustrate the fact that the distribution of the higher carbohydrates is an important factor governing the digestibility and thus the utilizable energy value of forage crops and that the use of this measure by both the agronomist and animal nutritionist should prove helpful in further studies of the production and utilization of forage crops. The chemical composition of these crops has a bearing also on the losses as heat which occur in the metabolism of the digested nutrients. But these losses are influenced by such a variety of interrelated factors, dietary and otherwise, that general statements to which the present review must be limited are of little value.

PROTEIN

It is well understood that a certain amount of protein is required in the rations of farm animals, the amount depending upon the purpose for which the ration is fed. An important advantage of legume over non-legume hay is its higher protein content, which means that less protein need be supplied in the concentrate mixture. This advantage may not exist at all, however, when pasture grass is considered, for all growing grass is rather rich in proteins. So far as is known, a protein content in excess of 16 to 18% in the dry matter of the rations of herbivora has no advantage for any purpose and there are conditions where a lower level will suffice. While a superior value in protein nutrition is frequently suggested for grass which contains 25% or even more of this nutrient, there is no basis for this belief where the grass constitutes the sole ration.

It must be immediately recognized, however, that it is inaccurate to speak of protein content in this way without certain qualifications. As thus commonly used, the term means nitrogen multiplied by the factor 6.25, but by no means all of this nitrogen is in protein form. Twenty-five to even 50% of the total nitrogen may be non-protein, chiefly amides and amino acids. Silage has a large amount of non-protein nitrogen, in part because of the stage of maturity at harvest, and especially because of changes occurring in the silo. The vital question with respect to the value of forage crops in protein nutrition is the significance of the forms of nitrogen present, in view of the modern knowledge that the adequacy of this nutrition is governed by the nature of the nitrogen compounds, especially the amino acids, in the feed.

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[3]Figures in parenthesis refer to "Literature Cited", p. 510.

Studies with rats, chickens, and man have shown that the value of a given source of protein is dependent primarily upon its supply of certain amino acids which are needed to form body proteins and which the body cannot manufacture. Thus it has come to be recognized that there are important differences in "biological value" of protein and other nitrogen compounds in feeds. We have little knowledge of the application of this concept to herbivorous animals particularly as regards the forage crops. Data for individual feeds are of limited value unless such a feed provides the sole ration because the biological value of a mixture cannot be assumed from data with respect to its constituents, due to the mutually supplementing action of various sources.

The early studies of Hart and Humphrey (4) with milking cows indicated that differences in protein value existed when certain concentrates were combined with non-legume roughages which did not occur when clover or alfalfa were used instead. Maynard and associates (8) were unable to find any superiority for a ration based on clover hay over one based on timothy hay where the protein intakes were held equal per unit of milk produced by appropriate adjustments in the grain mixture. With growing lambs, Turk and his associates (14) found no differences in the biological value of the protein of clover and alfalfa fed alone or in combination with corn.

Crampton (2, 3) has produced evidence that pasture grasses vary in protein efficiency for the growth of rabbits and that fertilization may be a factor concerned. Morris and associates (9) have reported that, as a supplement to a basal ration of straw, beet pulp, and oats, the protein of spring grass is superior to that of autumn grass for milk production. The general significance of these important observations must be tested by further studies.

The distribution of the nitrogen compounds in forage crops, as determined by chemical analysis, does not provide a basis for assessing their value in protein nutrition. The value of the protein present as such depends upon its amino acid make-up. The non-protein nitrogen which is present as amino acids may be just as valuable as the protein nitrogen, or even more so. Amides are not useless because they may be used by bacteria to build their body protein which is in turn digested to amino acids. Whether this process contributes in an important way to protein nutrition cannot be stated. It would be possible for the nitrate nitrogen to be utilized in this way. Neither chemical technics nor nutrition knowledge are adequate at the present time for estimating the protein values of feeds on the basis of determinations of their content of the various amino acids.

MINERALS

Of the dozen minerals required by the animal body all are present in forage in amounts which vary with the species and the stage of growth. Aside from those supplied by common salt, calcium and phosphorus are the only ones which are likely to be deficient in terms of the needs of the animal. The extent of their importance varies according to whether the forage is the sole ration or whether it is supplemented with concentrates or other feeds. In some cases the supple-

mentary feed may automatically take care of any deficiency in the forage while in other cases this deficiency may be intensified.

The effects of a low-phosphorus content in pasture grass and dry forage upon the appetite, growth, production, and reproduction of cattle and sheep are well known. The deleterious effects occur acutely where the dry matter contains 0.12% or less of the element. When forage constitutes the sole feed, a phosphorus content of at least 0.3% is needed during periods of maximum demand, such as growth and high milk production. When forage is supplemented with concentrates additional phosphorus is supplied in amounts which depend upon the nature of the supplementary feed. The liberal feeding of high-protein concentrates to milking cows, as is the common practice in the East, takes care of the phosphorus requirement even though the roughage contains little of the element. Where the concentrate consists entirely of corn or oats there will be a deficiency unless forage supplies a liberal amount.

In certain respects calcium presents the larger problem in practice because roughage is the only important source of this element in any ration for herbivora. No grains nor seed products are rich. The kind of roughage is the vital factor. Despite variations, legume hay and grass are always rich in terms of the animal's needs. Since this is true, a consideration of factors which influence their content of calcium is of minor importance. The situation is quite different for non-legume hay, particularly here in the East. It is believed that where this hay forms the basis of a dairy ration it should contain at least 0.35% of calcium Our studies indicate that much of the hay grown in New York State does not reach this figure. Fifty samples of timothy in full bloom were gathered from good and poor soils fertilized and unfertilized. On an air-dry basis the calcium content ranged from 0.14 to 0.35% with a mean of 0.24%. The dairyman who has this kind of hay must either grow some legume roughage to feed with it or else he must use a calcium supplement. These same samples of hay had a phosphorus content ranging from 0.13 to 0.28% with a mean of 0.22%.

There are no other minerals which require consideration in assessing the nutritive value of forage crops in the Northeast. While nutritional anemia can be experimentally produced in calves and lambs, it never occurs in practice in this area because the feed supply is always adequate in iron. Although goiter sometimes occurs in the newborn the iodine need is best taken care of by direct administration. Evidence indicates that the several other mineral elements required by the animal body are always supplied adequately by the commonly fed rations.

VITAMINS

There are at least seven definitely recognized vitamins. It is important to remember that all vitamins are not needed by all species and that even when needed their importance depends upon the likelihood of their being absent from the usual feeds. Only two vitamins have been proved to be required by herbivora. Perhaps the proof has been obtained for these alone because they are the only ones which are frequently deficient in the ration. It seems probable that certain others may be needed, although they are doubtless of no

practical importance in selecting rations because they are always present in adequate amounts.

All herbivora need vitamin A for growth and for reproduction and other functions throughout life. Forage crops are the principal source of this vitamin. No concentrate aside from yellow corn and a few uncommon feeds are rich. As a generalization, vitamin A activity is correlated with greenness and leafiness. Rapidly growing pasture grass is a rich source which serves to meet current needs and to provide a store in the body which can be drawn on later if the winter ration is deficient. Non-growing, dried up grass is very poor in the vitamin and severe losses in growth, reproduction, and lactation occur where it is the sole feed as has been shown by Hart and Guilbert (5).

Mature hay contains less vitamin A than does grass, but even at maturity legume hay is an excellent source and grass hay can be entirely satisfactory. Since the vitamin content decreases with maturity, early cutting is important. Even more important is the curing process. Long exposure and a loss of leaves means a large destruction of the vitamin. Field curing causes considerable loss at best. Artificial drying is much less destructive. Converse and Meigs (1) have shown that No. 3 timothy hay is so poor in vitamin A that the milk produced from cows fed on it will not support the growth of calves. A very poor grade of alfalfa hay may be inferior to a properly cured, early cut timothy. There is a gradual loss of the vitamin in storage with the result that old hay always contains less.

Silage may supply a considerable amount of vitamin A depending upon the stage of maturity, the amount of grain present, and the nature of the changes occurring in the silo.

Vitamin D is needed for the growth of all herbivora, but has little or no proved value as an aid to calcium and phosphorus nutrition in the mature animal. No amount will overcome the mineral losses which normally occur during heavy milk production and massive doses are required to increase markedly the vitamin content of the milk.

Animals which are regularly exposed to sunlight during the summer are adequately supplied with the vitamin in this way and the content in the feed requires no attention. In barn feeding the nature of the ration becomes important, and forage crops provide the only source of the vitamin unless special feeds like irradiated yeast are used.

The vitamin D content of forage depends entirely on exposure to the sun. The growing plant contains none of the factor, but it contains precursors which are transformed into the vitamin during sun curing. Thus the curing process is all important. Fairly rapid curing in bright sunlight gives the best results. Artificial drying produces a less potent product because of the limited exposure to the sun. On the other hand, prolonged exposure in the field is also deleterious, particularly if bad weather extends the curing process. When cured under the same conditions, legume hay develops much more vitamin D than does nonlegume roughage, but even the latter, if properly cured, can supply enough to meet the needs of the growing animal.

Silage contains a significant but variable amount of the vitamin, depending upon its exposure to the sun after cutting and before being placed in the silo.

A review of various experiments dealing with the vitamin content of forage crops as influenced by various factors is presented by Hunt and co-workers (6). They give the results of studies of the influence of stage of maturity and chemical composition upon the vitamin B (B_1) and G content of hays and pasture grass. At the present time it is not known whether either of these vitamins is required by herbivora.

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THE WINTERHARDINESS OF WEEDS[1]

S. T. DEXTER[2]

THE control of weeds in agricultural practice has been attempted in various ways and with various degrees of success. Detachment from the soil, smothering, the toxic effect of certain chemicals, exhaustion of organic foods, and drouth may be enumerated as among the more important hazards to which weeds are subjected either by nature or by the planned procedure of man.

In considering the hazards to which weeds might be subjected deliberately, it has seemed that more information in regard to their ability to endure cold might be useful. Certainly a common cause of death in crop plants is winterkilling and the degree of winter injury may be influenced by previous treatment such as the time or frequency of defoliation or fertilization.

In experiments with crop plants Steinmetz (4)[3] and Dexter, *et al.* (1, 2) have shown that they could not withstand cold in early fall, but that this ability increased greatly as winter weather came on. This point and others related thereto will be considered in this paper.

EXPERIMENTAL MATERIAL AND METHODS

The weeds studied were quack grass (*Agropyron repens*), Canada thistle (*Cirsium arvensis*), and field bindweed (*Convolvulus arvensis*), all perennials, and downy brome grass (*Bromus tectorum*), a winter annual. Two plats of quack grass were used one of which had been fertilized heavily with ammonium sulfate for the two previous years, while the other had been unfertilized. The thistle and bindweed were obtained from an old stand growing in sod, while the downy brome grass came from a small patch in oat stubble. Samples of rhizomes of quack grass, of roots of bindweed and thistle, and of crowns (leaf sheathes and young leaves that survive the winter) of downy brome grass were prepared at weekly intervals from October 7, to December 1. The weather during this period was about average, with heavy killing frosts October 25, 27, and 28. At this time, the downy brome grass was frozen back to the ground and some freezing of the soil occurred in exposed spots. After this date the weather became warmer, new leaves developed on the downy brome grass, and growing conditions prevailed until about November 13. After that date the ground was frozen in exposed areas. On November 24, the quack grass sod was just beginning to freeze, while on December 1, following several nights below 10° F, frost had penetrated to a depth of 3 or 4 inches.

To follow the hardening process in these plants, the method described by Dexter, *et al.* (1, 2) was used. Samples were dug, cut into lengths of about 3 inches, carefully washed and rinsed in distilled water, and permitted to dry under a moist cloth. In the case of quack grass and bindweed, an attempt was made to prepare samples of both old and new rhizomes and roots. Although the selection was rather arbitrary in the case of bindweed, it was relatively easy to distinguish quack

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[3]Figures in parenthesis refer to "Literature Cited", p. 517.

grass rhizomes formed during the summer and fall from those formed at earlier dates. Samples of 5 grams were prepared in the case of quack grass, thistle, and bindweed, and 1 gram in the case of downy brome grass. The weighed samples were placed in carefully washed pyrex glass tubes and were frozen at — 8° C for 4 hours by immersion of the tubes in an alcohol-water slush bath which was kept in a chamber at approximately that temperature. After freezing, the samples were placed in a water bath at 2° C and 50 cc of water at that temperature were added. After 20 hours of exosmosis in the samples, electrical conductivity measurements were made on the surrounding liquid. The sample, with the liquid, was then heated to boiling and returned to the 2° C bath, where extraction continued for 72 hours additionally, at which time a second reading of electrical conductivity was made. In this way some idea of the total amount of soluble electrolytes in the samples was obtained (3).

RESULTS

From each lot, except downy brome grass, one sample was planted in the greenhouse after freezing. Of the roots and rhizomes planted in the greenhouse, none sprouted or gave evidence of having survived the freezing treatment except samples of rhizomes from plants that were unfertilized. Two sprouts appeared on the samples frozen November 24 and several on those frozen December 1.

Table 1 shows the average specific conductivity of the samples of the various species following freezing and exosmosis.

TABLE 1.—*Specific conductivities ($x10^7$, 2°C) expressed in reciprocal ohms of extracts of weed samples frozen for 4 hours at -8°C, an interval of 20 hours being allowed for exosmosis at 2°C.*

Date	Quack grass rhizomes				Bindweed roots		Canada thistle roots, old	Downy brome grass, crowns
	Fertilized		Unfertilized		Old	New		
	Old	New	Old	New				
Oct. 8	1,017	3,015	1,311	2,588	2,709	3,750	6,375	1,735
Oct. 14	858	2,248	1,496	3,180	2,175	3,785	6,258	1,810
Oct 21	1,053	2,484	1,803	3,576	2,347	5,460	7,060	1,391
Oct. 28	768	1,500	1,292	2,415	2,274	3,815	5,417	898
Nov. 3	763	1,525	1,610	2,375	2,571	3,660	6,075	1,343
Nov. 10	637	1,376	1,346	1,935	2,807	2,980	7,410	1,250
Nov. 17	675	887	1,043	1,741	1,811	3,080	5,550	612
Nov. 24	567	750	917	1,566	1,217	2,250	5,473	——
Dec. 1	799	1,042	809	1,042	2,145	3,070	6,270	——
Dec. 1 (buried Oct. 14)	1,129	——	963	——	2,188	——	6,095	——

Table 2 gives the values for specific conductivity following boiling and exosmosis and table 3 gives the percentage of total electrolytes (as determined by boiling) that were extracted following freezing.

It was evident that these weeds showed about the same tendencies as alfalfa, winter wheat, red clover, etc. Canada thistle was notable in that it seemed to undergo little hardening and appeared to be sensitive to low temperatures even on December 1. In preparing the samples on this date, it was evident that many of the rhizomes of the fertilized

TABLE 2.—*Specific conductivities (x10[7], 2°C) expressed in reciprocal ohms of extracts of weed samples frozen and boiled and subsequently extracted for 72 hours at 2°C.*

Date	Quack grass rhizomes				Bindweed roots		Canada thistle roots	Downy brome grass, crowns
	Fertilized		Unfertilized		Old	New		
	Old	New	Old	New				
Oct. 8	3,000	6,940	4,480	6,300	3,875	4,710	6,800	2,435
Oct. 14	3,046	4,425	4,832	6,250	3,999	4,825	7,365	2,420
Oct. 28	2,718	4,040	4,997	5,800	3,745	4,830	5,955	1,454
Nov. 3	2,950	5,230	5,603	7,280	4,350	4,845	——	2,210
Nov. 10	2,650	3,992	4,420	6,355	4,535	4,645	7,592	2,480
Nov. 17	2,754	3,200	4,553	6,280	3,720	4,630	6,628	2,468
Nov. 24	2,853	3,270	4,730	5,740	4,110	4,840	6,725	——
Dec. 1	3,458	3,835	5,233	6,270	4,792	5,230	8,855	——
Dec. 1 (buried Oct. 14)	3,798	——	4,675	——	4,528	——	7,810	——

TABLE 3. *Percentage of total electrolytes extracted in 20 hours following freezing.*

Date	Quack grass rhizomes				Bindweed roots		Canada thistle roots	Downy brome grass, crowns
	Fertilized		Unfertilized		Old	New		
	Old	New	Old	New				
Oct. 8	33.9	43.4	29.3	41.2	70.0	79.7	93.7	71.2
Oct. 14	28.2	50.9	30.9	50.9	54.5	78.8	85.0	74.8
Oct. 28	28.3	37.1	25.9	41.5	60.7	78.8	91.1	61.8
Nov. 3	25.9	29.1	29.2	32.6	59.2	75.7	——	60.8
Nov. 10	24.0	34.5	32.8	30.4	61.9	64.2	97.5	50.3
Nov. 17	24.5	26.9	22.8	27.7	48.7	66.7	83.7	24.8
Nov. 24	19.8	22.9	19.4	27.3	29.6	46.6	81.4	——
Dec. 1	23.1	27.2	15.5	16.6	44.7	58.7	70.8	——
Dec. 1 (buried Oct. 14)	29.7	——	20.6	——	48.3	——	77.8	——

quack grass and the roots of Canada thistle and bindweed had been injured by freezing in the field. This is indicated in the data by the increased electrical conductivity on the last date, when greater exosmosis and a greater percentage extraction resulted in these samples.

On October 14, sods of quack grass were turned over and samples of thistle and bindweed roots were buried at a depth of about 6 inches to prevent photosynthesis during the fall months. The last figure in each column in the tables (Dec. 1, buried Oct. 14) shows the values obtained from these samples. It would appear that quack grass rhizomes from heavily fertilized plats did not harden at all from October 14 to December 1 when photosynthesis was prevented. The rhizomes from unfertilized plats hardened fairly well under these conditions, although not so well as when undisturbed. The same might be said for Canada thistle and for bindweed. During the fall, the quack grass rhizomes sprouted vigorously and these sprouts were cut off at the

surface of the ground once. By December 1 the same sprouts were again showing an inch or two above the ground. Those in the fertilized sod appeared to be killed back to the parent rhizome when the ground froze, while those on the unfertilized plants were uninjured.

In order to check on the injury from freezing in the field, samples were dug from the frozen ground on December 1, placed in mesh bags, and covered lightly with soil. These samples remained exposed to the weather from December 1 to December 15. During this time the ground remained frozen, although the air temperature was never as low as 10°F for more than an hour or two, and frequently went above 32°F. At least half of the time the samples were covered with snow. On December 15, part of the samples were put into a seed germinator on moist blotters to recover. All of the Canada thistle roots were dead, and many of the bindweed roots were dead, whereas most of the quack grass rhizomes sprouted.

COMPARISON OF ALFALFA WITH BINDWEED, QUACK GRASS, ETC.

On December 7, samples of roots and rhizomes of these weeds were dug from the frozen ground. The Canada thistle roots were usually dead if in frozen ground but were found mostly below the frost level Some of the bindweed roots in the uppermost layers appeared to be severely injured or dead At the same time, alfalfa crowns were chopped from the frozen soil. Samples were washed, thoroughly dried, placed in dry test tubes, and frozen in the alcohol slush bath for 8 hours at −2° C, −3° C, −4° C, −6° C, and −8° C. Two sets of samples were frozen at −4° and −6° C. One set was stirred occasionally with a glass rod, while the other set was kept as still as possible to favor supercooling without freezing.

At the end of 5 hours, the larger roots of thistle and bindweed appeared to be unfrozen in the −2 and −3° C treatments, even though they were shaken. In fact, it is doubtful whether all the pieces of the material in these samples ever did freeze. Even at lower temperatures, some pieces seemed to escape freezing. This may be due to the thorough surface drying that they received prior to being placed in the freezing baths. In each case, the alfalfa froze promptly, for with the alfalfa the buds and leaves at the crown remained somewhat moist.

After 8 hours in the freezing baths the samples were placed on blotters and put in a seed germinator. In the course of a few days, several facts were evident. The Canada thistle was completely killed at −6° and −8° and was severely injured even at −2° C. One plant of alfalfa was killed at −3° C, one at −6° C, and two at −8° C, but all the rest made a rapid growth of shoots. All quack grass samples frozen at −4° C or colder were injured and made less growth than the unfrozen check. The rhizomes from fertilized plats were all killed at −8° C and many rhizomes were killed at −6° C. The rhizomes from unfertilized plats survived the −6° C treatment fairly well, and about one third of those exposed to −8° C started to grow. The bindweed appeared hardier than the Canada thistle, but less hardy than the alfalfa or quack grass in unfertilized plats. No bindweed roots

survived —8° C and about one third survived —6° C. Stirring the samples usually resulted in greater injury at both —4° and —6° C.

EFFECT OF SPROUTING UPON HARDINESS AND ABILITY TO HARDEN

The results with field samples in this regard have been discussed above. Additional experiments were performed with roots and rhizomes that were sprouted in a seed germinator and then placed to harden at 2° C. Samples were dug October 7. Three series were run as follows: The first was hardened without sprouting, the second was hardened after 10 days of sprouting in the germinator, and the third after 20 days of sprouting. Without including the great detail of figures taken it may be said that sprouting greatly decreased the hardiness of both fertilized and unfertilized quack grass.

In the samples from fertilized plats, the ability to harden when subsequently placed at 2° C was completely eliminated. The samples from unfertilized plats sprouted far less profusely in the germinator and were less affected in hardiness than were the other samples. Even after 20 days of sprouting, the samples from unfertilized plats still retained considerable ability to harden at 2° C. These findings are in accord with the field data. The bindweed and thistle hardened rather better than the quack grass at 2° C. They, too, were adversely affected by sprouting, although to a lesser extent than the quack grass.

A FIELD EXPERIMENT

Several field experiments are in progress on these various points, but one may be described as virtually finished. In the early spring of 1935, plats of quack grass at Lake City (125 miles north of East Lansing) were fertilized with various amounts of ammonium sulfate up to 600 pounds per acre. The hay was cut from these plats just before heading out and the field was plowed for potatoes about June 20. Due to a very dry season, the stand of potatoes was relatively poor and a crop of about 130 bushels per acre was taken from the field. The quack grass was abundant in the field during the summer and fall. After harvest in October, the field was worked two or three times with a field cultivator and since the potatoes were dug with a power digger, the grass was left fairly well on the surface. There was an abundance of new rhizomes which were long and succulent. The potatoes were fertilized in addition with 400 pounds of 4-16-4 per acre.

The following spring the field was plowed to a depth of about 8 inches, given a normal seedbed preparation, and again planted to potatoes. The quack grass, meanwhile, dead for all practical consideration, completely disappeared. In the opinion of A. M. Berridge, Superintendent of the Lake City Experiment Station, the field was as clean and free from quack grass as if it had been summer fallowed and worked with a field cultivator all the previous summer. Further experiments are in progress, but it seems probable that much of this grass was killed or severely weakened by freezing due to its succulent condition and the lack of opportunity for photosynthesis during the late fall. Certainly it was not killed by drouth, nor did sprouting in

the brief and cool period between potato harvest and the time the ground froze by any means completely exhaust its food reserves.

SUMMARY

1. Samples of rhizomes from fertilized and unfertilized quack grass, roots of Canada thistle, and field bindweed and crowns of downy brome grass were collected at weekly intervals during the fall. Tests of their ability to endure low temperatures showed that they became more hardy as cold weather came on. Canada thistle was found to be relatively susceptible to injury by freezing.

2. If photosynthesis was prevented in the fall, quack grass fertilized with nitrogen failed to harden, while unfertilized quack grass rhizomes hardened considerably, although not as well as if photosynthesis was permitted.

3. Alfalfa roots and crowns were found to be able to withstand lower temperatures than Canada thistle or bindweed roots. Quack grass rhizomes from unfertilized plats were hardier than those from fertilized plats.

4. The applicability of some of these principles to the control of quack grass on a field scale is described.

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BOOK REVIEWS

MOISTURE AND FARMING IN SOUTH AFRICA

By W. R. Thompson. London: Gordon & Gotch, Ltd. 260 pages, illus. 1936. 21/6.

THIS rather unique book is Volume 14 in the South African Agricultural Series published by the Central News Agency, Ltd., of Johannesburg. The author is Senior Lecturer in Agronomy at the University of Pretoria.

The studies reported in this volume constitute a survey of the factors affecting the moisture supply of South African farming about which much erroneous speculation is current. The realization that land cannot be properly utilized without a thorough knowledge of rainfall and its dissipation has led to the present study. The volume deals with such subjects as the alleged drying up of South Africa and the drought problem, rainfall and its effects on farming and population movements, moisture dissipation and soil erosion, and the effects and trends of special practices in South African soil management.

The book should be especially interesting and helpful to any worker in technical agriculture and soil conservation, also to meteorologists, botanists, and forest workers. (R. C. C.)

SOIL CONDITIONS AND PLANT GROWTH

By Sir E. John Russell. New York: Longmans, Green and Co. Ed. 7. VIII + 655 pages, illus. 1937. $7.00.

EVER since this exceedingly valuable survey of the field of soil science in its relation to the growth of plants made its first modest appearance in 1912, its reappearance at various intervals has been eagerly looked forward to by all workers in this field throughout the world. From a monograph of 168 pages it has evolved in size and scope until it is generally regarded as the standard work of its kind. The recognized authority of its author gives the work dependability, while his style and selection of material give it readability. As the author states, he has tried to keep down the size of the book so that it will be read and not merely consulted like a dictionary.

A large amount of new material is presented in the new edition, in fact the author states that the changes are so considerable that much of the book had to be rewritten. The size of the volume has been kept within bounds by a critical selection of material, omitting the former appendix of analytical methods, and also by curtailing the bibliography.

In even a cursory examination of the book one is impressed with the tremendous advance which has been made in the field of soil science in the five years since the sixth edition was published. Any worker interested in the field of soils and plant science cannot afford to be without this new edition. (R. C. C.)

CONSERVATION OF THE SOIL

By A. F. Gustafson. New York: McGraw-Hill Book Company, Inc. 312 pages, illus. 1937. $3.00.

IT IS fortunate that the results of the long and intimate experience and association of the author with soil conservation work has been made available to the public in this excellent new book. In the preface the author states that the book "is presented for the use of land owners and operators, for those concerned with land mortgages, for general readers, for county agricultural agents, and for use in college and high school courses in soil conservation". This statement covers a rather wide range of workers, but the book well meets the requirements of each group mentioned and it should be the property of all others interested in soil conservation. There has existed an urgent need for just this sort of book.

The volume, consisting of 17 chapters, considers the extent and seriousness of erosion and its effect upon the social and economic conditions of past and present and its possible influence on the future welfare of farming and society in general. The various kinds of erosion and causes are discussed and well illustrated. The major portion of the volume, however, is devoted to the various means and methods of prevention and control of erosion on the farm lands of the United States. The author, being an agronomist, has given major consideration to agronomic aspects, but engineering features have not been neglected. The last two chapters are devoted respectively to "Control of Erosion on Public Highways" and the "Control of Floods".

The book is easy to read, abundantly illustrated, and will doubtless prove valuable in guiding the thought and activity of those dealing with soil conservation problems and giving the public a better conception of its interest in soil conservation. (D. R. D.)

THE NATURE AND PROPERTIES OF SOILS

By T. Lyttleton Lyon and Harry O. Buckman. New York: The Macmillan Company. Ed. 3. XIII + 392 pages, illus. 1937. $3.50

THE second edition of this well-known text appeared in 1929 and was reviewed in this JOURNAL (Vol. 22, page 190). So many advances have been made in our knowledge of soils since that time that a very thorough revision of the text was found necessary. It has been written primarily as a text book to be used for an introductory college course in soils. This imposes rather definite limitations on the size of the book. The new edition contains much new material, but the number of words contained is almost identical with the number in the previous edition. The format has been improved by increasing the page size and decreasing the thickness of the volume.

The subject matter has been thoroughly reworked. The number of chapters has been reduced from 18 to 17. A few new ones have been added and several old ones have been combined. A new chapter has been added on colloidal clay and ionic exchange. The chapters on soil water relationship have been reorganized but the treatment of the

subject follows rather closely the conventional lines. Considerable new material has been incorporated in the chapter on soil formation, classification, and survey.

Many changes have occurred in the last seven years in methods of manufacturing and using commercial fertilizers. The more important of these changes have been incorporated. But scant attention is given, however, to the great volume of very significant work on the localized placement of fertilizers. The treatment of the subject of soil acidity seems a little cumbersome due largely to the necessity of applying physico-chemical concepts which are unfamiliar to them ajority of undergraduate students in our colleges of agriculture. The chapter on "Methods of Fertility Maintenance for Mineral Soils" is placed at the end in this edition instead of in the middle as in the second edition. This seems a much more logical arrangement, for imparting information on methods of maintaining the fertility of the soil should be the chief objective of all teachers of edaphology.

Few errors were noted. The bentonites are classed as minerals instead of highly colloidal clays varying rather widely in chemical and mineralogical composition. As in the earlier editions copious references to the original literature are cited in footnotes so that the ambitious student will find the volume a useful guide into that larger field. The old edition has proved to be an exceedingly popular text. The new edition should hold all the old friends and make many new ones. (R. B.)

AGRONOMIC AFFAIRS

SUMMER MEETING OF NORTHEASTERN SECTION

THE summer meeting of the Northeastern Section of the Society will be held June 28 to 30, inclusive, and will include the inspection of agronomic work in progress in Massachusetts and New Hampshire. The group will meet at the Massachusetts State College at noon on Monday, June 28, and will spend the afternoon on the agronomy plots at the College. The banquet and annual business meeting of the Section will be held at Amherst that evening.

On Tuesday, June 29, field plots at Waltham, Mass., and Greenland, N. H., will be visited, with the trip terminating at Durham, N. H. Wednesday morning, June 30, will be spent in an inspection of the agronomy work at Durham, and the afternoon in optional tours to outlying experiments.

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THE EFFECT OF ORGANIC MATTER ON THE INFILTRATION CAPACITY OF CLARION LOAM[1]

F. B. SMITH, P. E. BROWN, AND J. A. RUSSELL[2]

EROSION may be defined as the removal of soil by water moving over the surface of the soil. Obviously, then, the water which percolates or filters into the soil decreases the amount which must pass over the surface of sloping land and any treatment of the soil which increases the amount of infiltration will decrease the extent of erosion. Musgrave[3] has shown that the infiltration capacity of the soil is one of the primary factors affecting the amount of surface runoff in the field. The infiltration capacity of a soil is a characteristic of the type but may be modified to some extent by certain soil management practices. It is well known that cultivation and the addition of organic matter to the soil decreases the volume weight and increases the porosity of the soil. Musgrave and Free[4] found that the infiltration capacity of Marshall silt loam was greatly increased when the porosity was increased.

The purpose of the present work was to study the influence of organic matter on the infiltration capacity of Clarion loam, using the method employed by these investigators.

EXPERIMENTAL

The experiments reported here were carried out on the 4-year rotation plats at the Agronomy Farm of the Iowa Agricultural Experiment Station. The soil is a rather uniform Clarion loam with an A horizon about 12 inches deep and a slope of about ½ to 2%. Plats 1100, 1101, 1105, and 1106 were selected for this study. Plats 1100 and 1105 are check plats. Plat 1101 has received 8 tons of manure and plat 1106 16 tons of manure per acre once in each rotation plowed under with the legume residues. The rotation consists of corn, corn, oats, and red clover and was

[1]Journal Paper No. J 447 of the Iowa Agricultural Experiment Station. Project 505. Received for publication March 19, 1937.

[2]Research Associate Professor of Soils, Professor and Head of Agronomy, and Research Fellow, respectively.

[3]MUSGRAVE, G. W. The infiltration capacity of soils in relation to the control of surface runoff and erosion. Jour. Amer. Soc. Agron., 27:336–345. 1935.

[4]MUSGRAVE, G. W., and FREE, G. R. Some factors which modify the rate and total amount of infiltration of field soils. Jour. Amer. Soc. Agron., 28:727–739. 1936.

initiated in 1914. The crop on the plats when these determinations were made was second year corn.

The method of procedure followed in these experiments was essentially the same as that reported by Musgrave. The cylinders used in this work for the determination of the infiltration capacity were cold drawn seamless steel tubing 6 inches in diameter and 14 inches long, with one end turned to a sharp edge. The cylinders were forced into the soil 12 inches by means of a jack screw set against a tractor. Two rows of five cylinders 3½ feet apart each way were put down on each plat. Five cylinders from each plat were dug out, the lower end cut off smooth, the cylinder and soil weighed for volume weight determinations and then placed in 1-gallon pots partly filled with soil. The pots with the cylinders of soil were then carried into the laboratory for the infiltration measurements. Infiltration measurements were made on the cylinders in the field for comparison with the measurements made in the laboratory.

The porosity of the soil was calculated from the relation $\frac{100\,(d - v)}{d}$, where d = density and v = volume weight. The organic carbon was determined by the dry combustion method.

RESULTS

The amount of water filtering into the soil in each cylinder in both the laboratory and the field determinations and the percentage of pore space of the soil used in the laboratory determinations are shown in Table 1. The data for the two check plats were averaged for comparison with the 8 and 16 tons per acre of manure (Table 2). An analysis of variance of the data is shown in Table 3. The average infiltration

TABLE 1.—*Infiltration rate in Clarion loam.*

Plat No.	Treatment	Cylinder No.	Infiltration rate—cc/2 hrs. Field	Infiltration rate—cc/2 hrs. Laboratory	Pore space Lab. soil %
1100	None	1	580	1,475	46.9
		2	980	2,150	46.9
		3	725	1,050	47.8
		4	625	275	44.7
		5	600	2,550	49.3
1101	8 tons manure per acre	1	970	1,075	45.4
		2	800	1,275	49.3
		3	2,450	1,510	46.9
		4	1,020	675	46.9
		5	700	1,405	48.5
1105	None	1	500	510	46.5
		2	410	1,940	43.9
		3	1,000	950	50.0
		4	925	1,000	45.4
		5	840	1,800	46.9
1106	16 tons manure per acre	1	2,720	1,740	48.1
		2	2,025	1,540	46.6
		3	575	1,200	46.6
		4	620	460	45.5
		5	3,940	1,540	47.0

capacity over a 2-hour period is shown in Table 4, and the infiltration capacity in surface inches is shown in Fig. 1.

TABLE 2.—*Average infiltration rate in Clarion loam and percentage of organic carbon.*

Treatment	Infiltration rate cc/2 hrs.		Organic carbon %
	Field	Laboratory	
Check	718.2	1,370.0	2.40
8 tons manure	1,188.0	1,188.0	2.38
16 tons manure	1,976.0	1,296.0	2.62

TABLE 3.—*Analysis of variance of infiltration rate.*

Source of variation	Degrees of freedom	Mean square	
		Field	Laboratory
Between treatments	2	2,640,262*	55,764
Within	17	627,165	372,621

*Significant.

TABLE 4.—*The infiltration capacity of Clarion loam in the field.*

Time in minutes	Surface inches infiltration, cumulative		
	Check*	8 tons manure	16 tons manure
5	0.59	0.66	0.70
10	0.73	0.86	0.96
20	0.88	1.18	1.48
30	1.03	1.44	1.84
40	1.11	1.66	2.18
50	1.20	1.85	2.50
60	1.31	2.02	2.88
70	1.38	2.28	3.25
80	1.44	2.45	3.52
90	1.52	2.61	3.82
100	1.60	2.83	4.08
110	1.64	2.98	4.40
120	1.71	3.06	4.65

*Average of check plats.

The data in the tables show considerable variation in the infiltration rate among replicate cylinders. The average infiltration rate on the two check soils under laboratory conditions was much greater than under field conditions, but this was not true for the manured soils. However, in other experiments not reported here, it was observed generally that the infiltration rate was more rapid when the determinations were made in the laboratory than when they were made in the field. The statistical analysis shows a significant difference in the infiltration rate between the treated and untreated soils when the determinations were made in the field, but the differences were not significant when the determinations were made in the labo-

ratory. The porosity of the soil as determined in these experiments was not significantly correlated with the infiltration rate.

The soils in cylinders which showed high infiltration rates were examined after the determinations to see if any explanation could be found for their difference in behavior. In one of the cylinders ex-

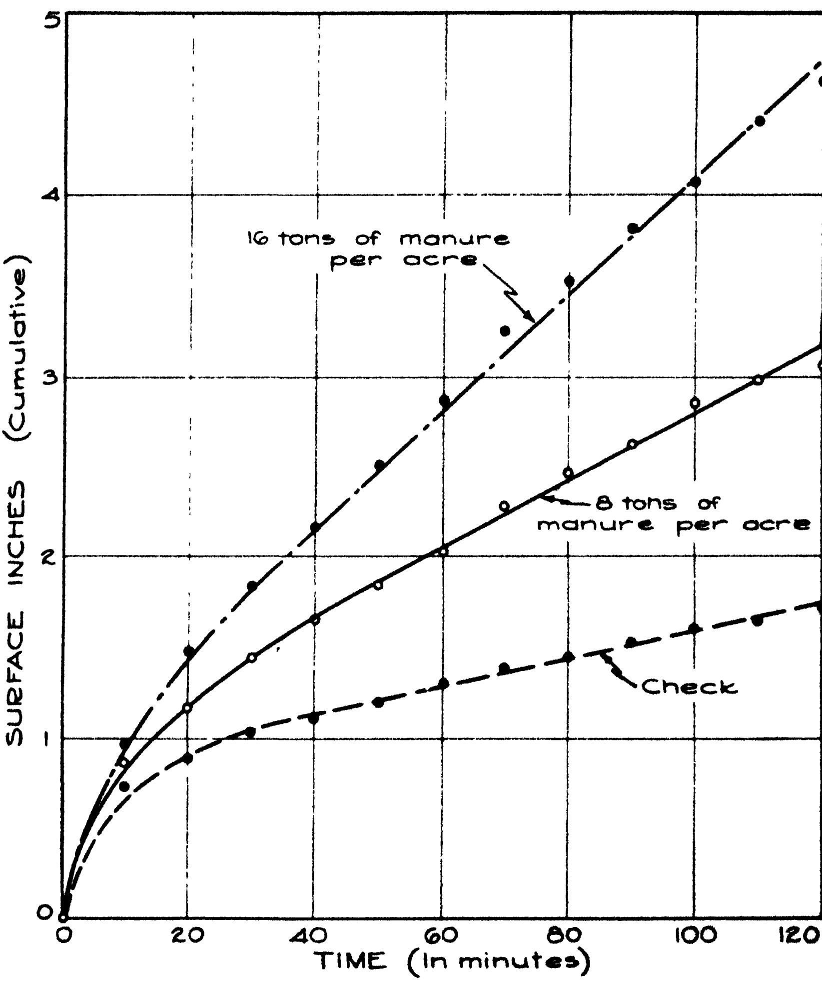

FIG. 1.—Infiltration capacity in surface inches in Clarion loam.

amined a piece of cornstalk was found standing upright in the soil. The pith of the cornstalk was fairly well decayed and it formed a tube about 1 inch in diameter which might have been partly responsible for the high infiltration rate in this cylinder. In other cylinders examined earthworm holes were abundant which undoubtedly explain in part the large variation in infiltration rate between cylinders on the same treatment.

The more rapid infiltration rate in the soils in the laboratory over that in the field was undoubtedly caused by the greater ease in the replacement of air in the soil pores in the laboratory than in the field. This does not mean, however, that a modification of the method cannot be employed in the laboratory. It might be that more than five cylinders of soil will be necessary for a laboratory determination, and perhaps that it will be necessary to seal the bottom of the cylinders. This would force the air through the soil-water column, a condition similar to that existing in the field, especially during a rain.

The failure of the infiltration rate to be correlated with the porosity of the soil is undoubtedly explained by the lack of an accurate determination of the porosity. The core of soil removed in the cylinder was 12 inches deep, and the average volume weight of five such cores from plat 1106 was 1.40, whereas, a volume weight determination made on a core of the same soil from the surface 5½ inches was 1.33. The volume weight of these soils to plow depth was considerably different from that at lower depths.

SUMMARY

Infiltration measurements were made on manured and unmanured Clarion loam in field and laboratory determinations. The results obtained may be summarized briefly as follows:

1. Large variations in the infiltration rate among replicate samples of soil were evident in both laboratory and field determinations.
2. Even though there was a considerable variation in the rate of infiltration among replicate samples of soil, the differences between manured and unmanured soils were significant when the determinations were made in the field.
3. The infiltration capacity of Clarion loam in a 4-year rotation of corn, corn, oats, and clover was found to be relatively high, but it was increased materially by additions of manure.

SOIL LIMING INVESTIGATIONS: III. THE INFLUENCE OF CALCIUM AND A MIXTURE OF CALCIUM AND MAGNESIUM CARBONATES ON CERTAIN CHEMICAL CHANGES OF SOILS[1]

JAMES A. NAFTEL[2]

WHEN liming materials are added to soils in excess of their exchange capacities, considerable changes may be induced in the active or exchangeable ions of the soil system. Also, since the addition of lime to soils changes the H-ion concentration, the solubility of many of the chemical compounds is altered and consequently the availability of plant nutrients is affected. It would be of value, therefore, to determine the extent of the changes when soils are systematically limed with increasing increments to the point where an excess of lime is present. Such a study on soils of different texture, chemical composition, and parent material should yield fundamental information on the rôle of lime in widely varying soils.

For brevity, references are made to only a few of the recent investigations which contain bibliographies of most of the outstanding contributions pertinent to the subject matter (2, 4, 10, 11, 17, 18).[3]

PLAN OF INVESTIGATION

This study was facilitated by use of the $CaCO_3$ equilibration method of liming (6) by which the soils were limed in increments to the point of and beyond saturation. This permitted a study of various degrees of saturation with bases and of the maximum range of soil reaction (from liming materials) as they affect the distribution and solubility of compounds. The specific topics studied in this investigation included the H-ion concentration, residual carbonates, exchangeable Ca, K, and Mn, soluble Ca and P, and base exchange capacity.

The eight soils studied (Table 1) vary widely in many of their properties and represent the lower and upper Coastal Plains, the Piedmont Plateau, Appalachian Mountains, and Limestone Valley Provinces.[4]

The Ca sorption capacities of the soils were determined as previously described (6), and the soils were limed in the greenhouse as follows: (a) $CaCO_3$ (C. P.) was added to bring the soils to 25, 50, 75, 100, and 125% of the Ca sorption capacity; and (b) $CaCO_3$ and $MgCO_3$ (C. P.) in equivalent amounts were added to bring the soils to 50 and 75% saturation. Greenhouse studies of the unlimed soil and of the soils limed in the field were also made.

The arrangement of the experiment and the amounts of lime added are shown in Table 2. All treatments were in duplicate on 8 kilos of air-dry soil.

Six successive crops, including both leguminous and non-leguminous plants, were grown on the soils. Nitrogen and potassium were added to the soils in suffi-

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[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director as Part III of a series. Received for publication March 27, 1937.

[2]Assistant Soil Chemist.

[3]Numbers in parenthesis refer to "Literature Cited", p. 535.

[4]The soils selected for this study were taken from Plots 4 and 8 of the two-year rotation experiments and Plot 4 of the old sources of nitrogen experiment of the Alabama Agricultural Experiment Station fields.

TABLE 1.—*Description and location of soils used in this investigation.*

Soil type*	Soil No.	Location†	pH	Exchange capacity, M.E.	Exchangeable Ca, M.E.	Ca saturation, %	Ca sorption capacity, %
Norfolk SL	940	Brewton, F	5.55	4.40	1.17	26.6	16.7
Norfolk SL.	941	Andalusia, F	5.35	3.25	0.51	15.7	11.6
Norfolk SL	942	Wiregrass, S	5.80	4.75	1.33	28.0	22.2
Hartsells FSL. . . .	943	Sand Mountain, S	5.88	3.85	1.61	41.8	29.4
Kalmia FSL	945	Aliceville, F	5.95	4.10	1.81	44.2	31.8
Decatur CL	946	Alexandria, F	5.82	10.30	4.21	40.8	35.0
Decatur CL	947	Tenn. Valley, S	5.81	8.85	3.54	40.0	31.3
Cecil SL .	948	Auburn, M	4.75	4.05	0.31	7.6	4.4

*SL = sandy loam; FSL = fine sandy loam; and CL = clay loam

†F, S, and M refer to Experimental Field, Substation, and Main Station, respectively, of the Alabama Agricultural Experiment Station.

TABLE 2.—*Amounts of lime added and arrangemnt of greenhouse experiment.**

Soil No.	Kind and amount of lime added in terms of percentage Ca-sorption capacity								
	Native	$CaCO_3$					Ca.Mg		Ca or Mg in field
		25	50	75	100	125	50	75	
940 .	0	0.58	2.33	4.08	5.88	7.58	2.33	4.08	2.00
941 . .	0	0.58	1.68	2.78	3.88	4.97	1.68	——	4.00
942	0	0.17	1.67	3.17	4.65	6.17	1.67	3.17	4.00
943 . . .	0	0	1.13	2.50	3.88	5.25	2.50	3.88	4.00
945 . .	0	0	1.03	2.45	3.88	5.30	1.03	——	2.00
946	0	0	1.79	4.79	7.76	10.79	1.79	4.79	2.00
947 . . .	0	0	2.12	4.95	7.76	10.60	2.12	4.95	4.00
948	0	1.51	3.34	5.17	7.00	8.83	3.34	5.17	——

*M E per 100 grams

$\frac{\text{M.E}}{2}$ = Tons $CaCO_3$ per acre.

cient amounts to remove these nutrients as limiting factors in growth of the plants. An initial application of 400 pounds per acre of 16% superphosphate was added to the first crop, and this treatment was not repeated until the fourth crop was planted; thus the residual phosphorus could be studied during the second and third crops. After each crop was harvested, the soils were dried, screened, mixed, and samples taken for the laboratory analyses. The growth of crops and the plant composition as affected by lime are reported in a subsequent paper.

RESULTS

SOIL REACTION

Change in reaction with time.—Samples of the soils were taken at monthly intervals and the pH values were determined with the glass electrode. Table 3 shows the pH values of the eight soils at different

Ca saturations one month after liming. The values increased practically linearly from the native saturation through 75% Ca saturation and reached a maximum and remained practically constant at 100 and 125% Ca saturation. This indicates that the method is accurate for determining the $CaCO_3$ equilibrium point of the soils. The pH values further show that there was rapid decomposition of the Ca and Mg carbonates. The addition of the Ca or Ca.Mg carbonates in equivalent amounts gave similar pH values.

TABLE 3.—*Reaction (pH values) of greenhouse soils one month after liming.*

Soil No.	Kind and amount of lime added in terms of percentage Ca-sorption capacity								
	Native	$CaCO_3$					Ca.Mg		Field limed
		25	50	75	100	125	50	75	
940	4.70	5.07	6.20	7.30	7.82	7.85	6.42	7.15	5.25
941	5.00	5.40	6.25	7.15	7.70	7.90	6.50	—	5.40
942	5.20	5.25	6.25	7.25	7.75	7.80	6.50	6.85	6.13
943	5.35	—	6.20	7.25	7.84	7.90	6.35	7.60	6.60
945	5.35	—	6.42	7.70	7.72	7.90	6.54	—	7.32
946	5.50	—	6.28	7.25	7.80	7.90	6.45	7.35	6.32
947	5.30	—	6.20	7.20	7.65	7.72	6.04	6.90	6.00
948	4.20	5.18	6.38	7.40	7.48	7.48	6.30	7.40	—

Since the changes in reaction of all the soils were in general similar, the pH values of only two soils are given after the one-month period. The pH values of Norfolk sandy loam (No. 940) and the Decatur clay loam (No. 946) are shown graphically in Fig. 1. The values shown were obtained after the soils were limed one month and after the removal of several crops in the greenhouse. The pH values of the limed soils continued at approximately the same level as the one-month values until the third crop was harvested. A decided "break" in the pH values was observed at that time and the soils continued to become more acid as long as the experiment was continued. The Norfolk sandy loam with its lower buffer capacity became more acid than the heavier Decatur clay loam. The increase in acidity was due mainly to the acidic fertilizer residue and to the removal of bases by the crops. The reaction of soils limed to relatively high degrees of saturation may be considerably influenced by the CO_2 partial pressure of the soil system, and this factor should be considered especially where an attempt is made to lime to definite pH values.

Effect of CO_2 partial pressure on the commonly used "Liming Factor".—Many of the proposed lime requirement methods (3, 9) make use of a liming factor in order that the greenhouse or field liming results will be comparable with the laboratory results. The work reported here indicates that the liming factor, in part at least, may be erroneous due to the failure of the investigator to consider the CO_2 partial pressure in the system. As previously shown (6), the pH values depend very definitely on the CO_2 partial pressure, especially when $CaCO_3$ is pre-

sent, and are comparable only when they are at the same CO_2 partial pressure. In the air-calcium-soil equilibrium method, the CO_2 content is held constant, equal to that of the atmosphere (0.0003 of an atmosphere). It is necessary, therefore, to equilibrate the soil suspensions with the air before determining the pH values. The values for the laboratory equilibration curve, before and after equilibration, are shown graphically in typical examples in Fig. 2. These data show quite

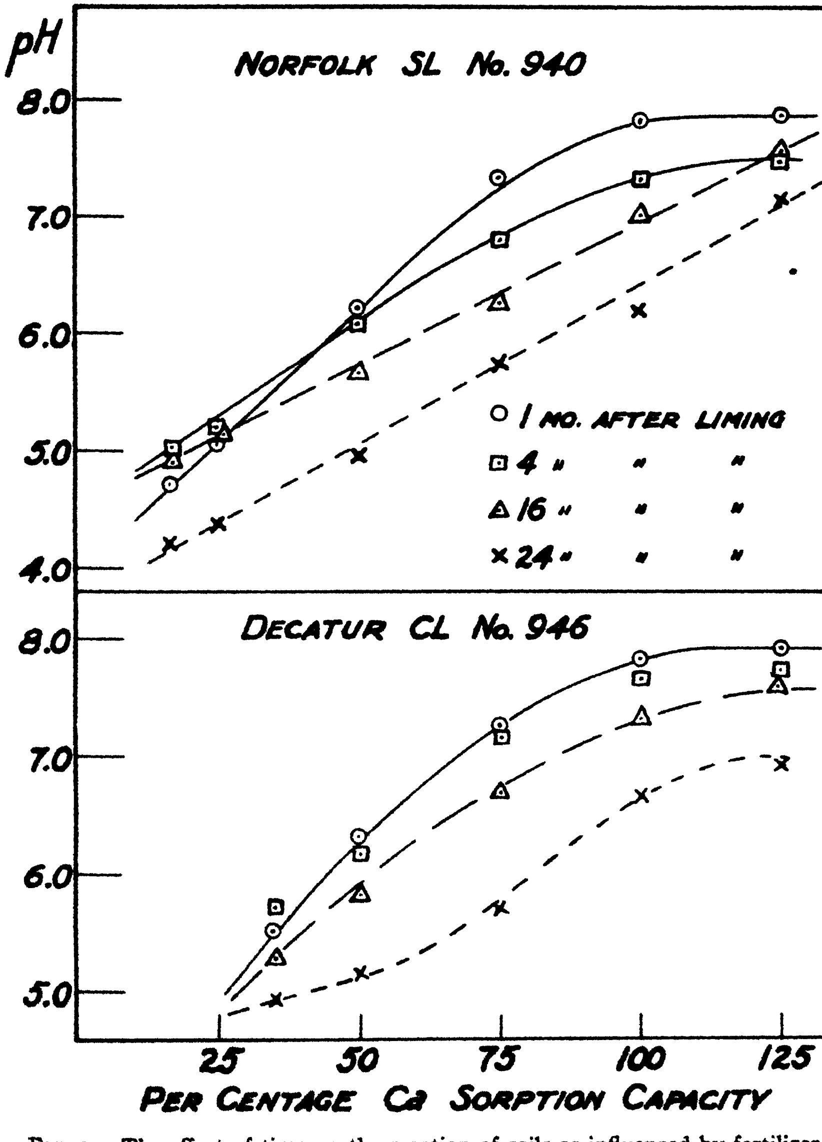

FIG. 1.—The effect of time on the reaction of soils as influenced by fertilizer residue and removal of bases.

distinctly the apparent error in the use of the liming factor when precipitated $CaCO_3$ is used as the liming material.

DISTRIBUTION OF CALCIUM IN SOIL

In order to determine the distribution of the Ca added to the soils, analyses were made for residual carbonate and H_2O-soluble and exchangeable Ca. These studies were made on all the soils at both 4 and 12 months after applying the liming materials to the soils. For the

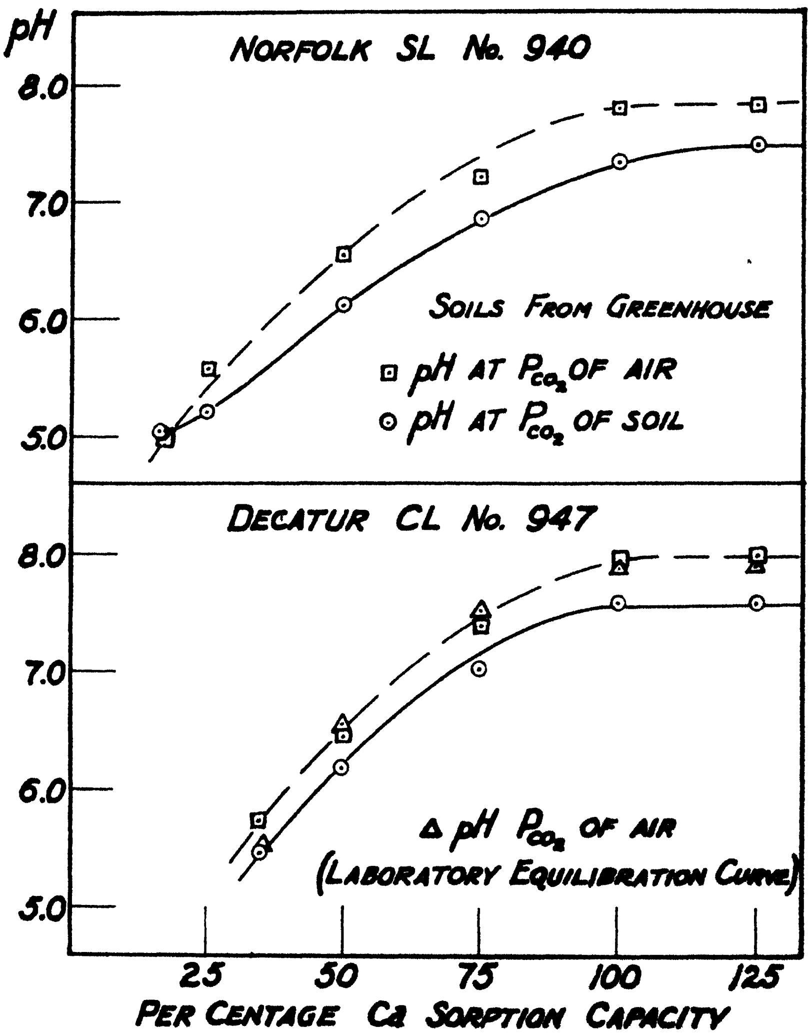

FIG. 2.—The influence of carbon dioxide partial pressure (P_{CO_2}) on the pH values of soils.

sake of brevity, representative data for only four soils, obtained when the soils had been limed 4 months, are given in Table 4.

Residual carbonates.—Schollenberger's method (12) was used throughout this investigation for determining the residual carbonates in the soils at different intervals. From Table 4, it may be seen that practically all of the lime added to the soils up to 50% saturation had decomposed, but only 70 to 90% of that added in amounts equal to the saturation capacity had decomposed at the end of 4 months. The total amounts of carbonates decomposed were directly proportional to the exchange capacity of the soils; thus, the decomposition of 125% saturation for the Hartsells fine sandy loam was 2.75 M. E. per 100 grams of soil; and for the Decatur clay loam, 6.04 M. E. There were practically equal amounts of carbonates decomposed at the saturation point and at 125% saturation.

Exchangeable Ca.—The increments of lime increased the exchangeable Ca directly with the amounts added up to the point of saturation. Where there were considerable amounts of free carbonates in the soil, the values for exchangeable Ca were somewhat low due to the solubility of the carbonates in the ammonium acetate. This made it necessary to obtain the exchangeable Ca values by difference between the Ca present in the ammonium acetate extract and that found as free carbonates. Accordingly, the proportion of ammonium acetate solution to soil should be increased where there are free carbonates in the soil to dissolve in the extracting solution.

The increase in exchangeable and H_2O-soluble Ca in the limed soils over that of the unlimed soils was found to be approximately equal to the amount of lime decomposed in the soils at the lower degrees of saturation. This was not true at the heavier rates of liming as seen in Table 4. Evidently some of the decomposed lime is fixed in the soil in forms which were not exchangeable with the ammonium acetate. It is impossible from the present data to distinguish between insoluble Ca compounds and non-exchangeable Ca silicates. Exchangeable Ca values obtained after the soils had been limed 12 months had increased slightly at the higher rates of liming, but there was little or no change at the lower rates.

INFLUENCE OF LIME ON OTHER IONS

Effect on soluble phosphates.—The readily available P by Truog's method (16) was greatly increased by liming. This was found to be true in all cases and at both 4 and 12 months after liming. The P soluble in the 0.002 N H_2SO_4 at 12 months, which was obtained after the third crop was harvested, is given in Table 5. The P increased directly with the amount of lime added and in most instances the soils limed to the saturation point contained about twice as much soluble P as the unlimed soils. It should be remembered that this is the residual P from an initial application of superphosphate to the first crop in the greenhouse. There were slight differences in the amount of P in the Ca- and Ca.Mg-limed soils at the same rate of liming. It appears from these data that the Ca phosphates are more soluble, even where free CO_3 is present, than are the native phos-

TABLE 4.—*The lime status of greenhouse soils four months after liming.**

Per cent saturation and kind of lime	Lime added	Lime decomposed	Exchangeable Ca†	Increases in exchangeable Ca†	H_2O soluble Ca	Lime added	Lime decomposed	Exchangeable Ca	Increase in exchangeable Ca†	H_2O soluble Ca
	Soil No. 942					Soil No. 943				
Native	0	—	1.08	—	0.20	0	0	1.50	—	0.19
25 Ca	0.17	0.17	1.02	0.00	0.17	—	—	—	—	—
50 Ca	1.67	1.67	2.36	1.28	0.23	1.13	1.13	2.50	1.00	0.22
75 Ca	3.17	3.02	3.55	2.27	0.31	2.50	2.10	2.90	1.40	0.32
100 Ca	4.65	3.80	3.35	2.23	0.33	3.88	2.63	3.70	2.20	0.35
125 Ca	6.17	3.92	3.10	2.02	0.34	5.25	2.75	4.10	2.60	0.40
50 Ca. Mg.	1.67	1.67	1.40	0.32	0.16	1.13	1.13	2.20	0.70	0.21
75 Ca. Mg.	3.17	2.97	2.00	0.92	0.16	2.50	2.50	2.60	1.10	0.22
Field limed	—	—	1.35	0.27	0.23	—	—	2.25	0.75	0.14
	Soil No. 945					Soil No. 946				
Native	0	—	1.95	—	0.14	0	—	4.05	—	0.21
25 Ca	—	—	—	—	—	—	—	—	—	—
50 Ca	1.03	1.03	2.95	1.00	0.20	1.79	1.59	5.00	0.95	0.25
75 Ca	2.45	2.35	3.50	1.55	0.39	4.79	4.14	7.75	3.70	0.42
100 Ca	3.88	3.68	4.60	2.65	0.50	7.76	5.56	9.45	5.40	0.53
125 Ca	5.30	2.45	4.20	2.25	0.49	10.79	6.04	8.20	4.15	0.64
50 Ca. Mg	1.03	1.03	2.55	0.60	0.19	1.79	1.79	5.90	1.85	0.24
75 Ca. Mg	—	—	—	—	—	4.79	4.29	7.10	3.05	0.56
Field limed	—	—	3.20	1.25	0.23	—	—	7.00	2.95	0.29

*Values in M.E. per 100 grams of soil.
†(Ca in NH_4Ac ext.)—(Ca as free CO_3).

phates, in the 0.002 N H_2SO. Other investigators have shown that water-soluble P (15) as well as that assimilated by seedlings (14) is increased by liming. An attempt was made to clarify the lime-phosphate problem in an earlier investigation (7).

TABLE 5.—*Readily available phosphate in greenhouse soils 12 months after liming.**

Soil No.	Kind and amount of lime added in terms of percentage Ca-sorption capacity								Field limed
	Native	$CaCO_3$					Ca.Mg		
		25	50	75	100	125	50	75	
940	15.0	24.0	24.0	30.0	40.0	48.0	31.2	32.0	30.0
941	20.5	22.4	32.0	35.2	36.8	44.8	25.6	——	19.2
942	28.8	36.8	41.6	64.0	64.0	83.2	41.6	44.8	35.2
943	16.0	——	16.0	22.2	30.4	30.4	20.8	20.8	19.2
945	14.4	——	17.6	22.4	25.6	25.6	14.4	——	25.6
946	13.4	——	18.4	22.4	27.2	27.0	16.0	22.4	19.2
947	11.2	——	12.5	17.6	20.8	23.2	12.0	——	——
948	13.6	16.0	20.8	30.4	35.8	44.8	22.4	28.0	——

*p.p.m. of P in air-dry soil

Effect on exchangeable potash.—The soils were analyzed after the third crop for exchangeable K. Ammonium acetate was used for the replacing agent and the KI method (1) for the determination of K. The results presented in Table 6 show that the Ca lime replaced the K directly with the amounts of lime added, while increases were obtained with the CaMg lime. An excellent opportunity was offered to study the effect of lime on exchangeable K in soils extremely low and high in K. The Norfolk series is characterized by low K content while that of the Decatur series is high.

TABLE 6.—*Exchangeable potash in greenhouse soils 12 months after liming.**

Soil No.	Kind and amount of lime added in terms of percentage Ca-sorption capacity								Field limed
	Native	$CaCO_3$					Ca.Mg		
		25	50	75	100	125	50	75	
940	12.0	8.0	7.5	6.5	5.5	5.0	16.0	14.0	6.5
941	10.0	7.8	8.0	7.6	7.4	6.8	27.5	——	11.5
942	9.2	17.0	11.0	8.0	7.0	6.0	25.0	37.0	20.0
943	20.0	——	15.0	14.0	10.0	14.5	29.0	32.5	32.8
945	30.0	——	20.0	13.0	9.8	8.0	37.2	——	19.0
946	94.0	——	130.0	113.0	91.0	60.0	160.0	133.0	111.0
947	65.0	——	52.0	34.4	28.8	32.0	82.0	——	——
948	5.9	6.0	6.5	5.5	6.6	6.6	25.0	22.0	——

*p.p.m. of K in air-dry soil.

The decrease in exchangeable K is due to the replacement of the K by the Ca ions (8). The K content of the Cecil sandy loam was so low that the method of analysis used did not show its replacement by the

Ca. It is interesting to note that the Ca.Mg lime additions increased the exchangeable K considerably; no explanation is offered for this observation.

Effect on exchangeable Mn.—It is well established that the exchangeable Mn in soils is reduced by heavy liming (5). The results given in Table 7 are in accord with the previous results on this subject. In several of the soils there was no exchangeable Mn detected at the two highest Ca saturations. The Mn is replaced by the added Ca and Mg and is further depleted by the insolubility of Mn in alkaline reactions.

TABLE 7.—*Exchangeable manganese of greenhouse soils 12 months after liming.**

Soil No.	Kind and amount of lime added in terms of percentage Ca-sorption capacity								Field limed
	Native	$CaCO_3$					Ca.Mg		
		25	50	75	100	125	50	75	
943	0.090	——	0.060	0.016	0.00	0.00	0.035	0.025	0.065
945	0.600	——	0.175	0.050	0.022	0.022	0.180	——	0.038
946	0.375	——	0.035	0.00	0.00	0.00	0.028	0.00	0.070
947	0.550	——	0.225	0.085	0.00	0.00	0.520	——	——
948	Trace	Trace	0	0	0	0	——	——	——

*M.E. of Mn per 100 grams of soil.

Effect on base exchange capacity.—The exchange capacities of the soils treated with $CaCO_3$ were determined to note if there had been changes due to liming. The results in Table 8 show an appreciable change in all of the soils except Nos. 940 and 946 in that the exchange capacity increased with liming. This was especially noticeable with the high saturations. Attention has been called to this effect by several investigators (13, 17) who have attributed it to a slight breakdown or destruction of the minerals present and to a build-up of the exchange complex in the alkaline medium. It seems, however, that a more plausible explanation would be that increases in organic matter

TABLE 8.—*Base exchange capacity of greenhouse soils 12 months after liming.**

Soil No.	Kind and amount of lime added in terms of percentage Ca-sorption capacity					
	Native	$CaCO_3$				
		25	50	75	100	125
940	3.28	3.32	3.28	3.24	3.22	3.24
941	2.22	2.10	2.10	2.30	2.40	2.50
942	3.42	3.33	3.34	3.38	3.72	3.88
943	2.56	——	2.76	2.80	2.96	2.84
944	3.13	——	3.58	3.72	3.60	3.60
946	10.38	——	9.94	10.36	10.34	10.38
947	8.60	——	8.88	9.14	9.50	10.00
948	3.62	3.76	3.80	4.00	4.16	3.96

*M E. bases per 100 grams of air-dry soil.

resulting from a greater amount of roots caused an increase in exchange capacity.

SUMMARY

A study was made of the changes induced in certain chemical properties of eight typical soils of Alabama when these soils were limed in increasing increments with $CaCO_3$ and $Ca.Mg(CO_3)_2$. The soils were limed in the greenhouse after which six successive crops were grown. At certain intervals during this time, samples of soils were removed from the greenhouse pots and analyzed for H-ion concentration, residual CO_3, H_2O-soluble and exchangeable Ca, exchangeable K and Mn, soluble P, and base exchange capacity. The results may be briefly summarized as follows:

1. The reaction of the soil changed linearly through the point of 75% of the Ca sorption capacity and then approached a maximum of approximately pH 8.0 at the equilibrium or saturation point.
2. The decomposition of $CaCO_3$ increased regularly with the increments of lime added until the saturation point was reached.
3. The increase in exchangeable and water-soluble Ca accounted for practically all of the $CaCO_3$ decomposed at the lower increments, but this was not true at the higher increments of liming. A portion of the Ca of the decomposed $CaCO_3$ was converted to the non-exchangeable forms.
4. Readily soluble P was more than doubled by the added lime.
5. Exchangeable K was decreased with each increment of $CaCO_3$ but for some unknown cause increased with the $Ca.Mg(CO_3)_2$ additions.
6. Lime replaced the exchangeable Mn directly with the amount added; in some instances no Mn was found after heavy liming.

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SOIL LIMING INVESTIGATIONS: IV. THE INFLUENCE OF LIME ON YIELDS AND ON THE CHEMICAL COMPOSITION OF PLANTS[1]

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THE main purpose of liming soils is to increase crop yields. Generally, the use of lime on acid soils has increased the yields of crops and hence was a desirable practice, but in some instances decreased yields have been observed (6, 7).[3] It is important, therefore, to know the optimum amount of lime to use for a definite cropping system on a given soil.

The composition of plants is important from the standpoint of quality or the nutritional value for animals. Under some soil conditions actual mineral deficiencies occur in feeds grown on certain soils (1, 3), and excessive liming may bring about similar conditions. Numerous investigations have been reported to show that liming influenced the mineral and protein content of crops (4, 8, 9), but further information is needed for a clearer understanding of the effect of lime on the chemical composition of plants.

In a previous paper (5), it was shown that lime effected certain chemical changes in soils, and it is the purpose of this paper to present the results on another phase of the same investigation in which a study was made on the influence of lime on yields and the composition of plants.

PLAN OF INVESTIGATION

Details of the soils used and the method of liming the soils in the greenhouse are given in the preceding paper (5). Briefly, this consisted of liming soils from eight different locations in Alabama in increments of 25% of the Ca-sorption capacities over the range from native saturation to 125%. Greenhouse studies were also included on soils limed in the field. The sources of lime were C. P. $CaCO_3$ and a mixture of C. P. $CaCO_3$ and $MgCO_3$ in chemically equivalent amounts. Six successive crops, consisting of Austrian winter peas, rape, sorghum, hairy vetch, sorghum, and early *Crotalaria spectabilis* were grown in the greenhouse in the order named.

When a majority of plants had made their maximum growth, each crop was harvested and the dry weight obtained. The third successive crop, which was sorghum, was ground in a Wiley mill and analyzed for ash, N, Ca, Mg, K, Mn, P, and Fe.

Since over-liming injury is somewhat temporary (6), the response of each successive crop to lime is discussed separately to bring out the effect of time on the growth response.

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[3]Figures in parenthesis refer to "Literature Cited", p. 547.

RESULTS

RESPONSE OF CROPS TO LIME IN THE GREENHOUSE

Growth of Austrian winter peas, first crop.—Peas were grown on these soils after an application of 600 pounds per acre of a 6–10–4 fertilizer. The yields are shown in Table 1. Moderate growth was obtained on all the soils, including the unlimed soils. The growth usually attained a maximum at 75% Ca saturation, and at higher degrees of saturation there was slight liming injury. The Ca.Mg lime was generally more effective than $CaCO_3$ in increasing the crop yields. This effect was probably due to the low content of Mg in many of the Alabama soils (2), and possibly to an increased efficiency of P where Mg was added (see below). The response of Austrian winter peas to lime on the light-textured soils was quite favorable. At 50% Ca saturation, increased yields of approximately 30% were obtained over the unlimed soils.

TABLE 1.—*Dry weights of Austrian winter peas (first crop) on greenhouse soils.**

Soil type†	Soil No.	Percentage Ca-sorption capacity: Native	Limed with $CaCO_3$: 25	50	75	100	125	Ca.Mg: 50	75	Field limed
Norfolk SL	940	6.10	6.20	8.10	6.00	5.50	4.10	7.00	7.70	6.30
Norfolk SL	941	6.50	8.90	8.70	9.20	5.60	5.60	9.40	——	7.70
Norfolk SL	942	5.10	4.10	6.30	7.80	7.40	6.70	6.40	7.00	7.00
Hartsells FSL ...	943	8.80	——	8.80	10.50	10.20	10.20	11.80	12.80	12.30
Kalmia FSL.	945	7.80	——	8.20	5.20	5.30	7.50	8.20	——	7.00
Decatur CL.	946	7.60	——	8.60	8.50	7.60	7.70	8.10	8.00	7.50
Decatur CL .	947	9.50	——	8.90	8.80	9.00	9.60	8.70	10.90	5.20
Cecil SL	948	4.90	6.60	6.60	6.60	6.10	6.60	8.00	8.80	——

*Grams per pot.
†SL = sandy loam; FSL = fine sandy loam; CL = clay loam.

Growth of rape, second crop.—This crop was planted 4 months after the soils were limed. Since the maximum response to lime in general was similar to that of the previous crop, the yields are not given. The increase in yields amounted to as much as 80% on the light and 30% on the heavy soils at 75% saturation.

Growth of sorghum, third crop.—The yields of sorghum are shown in Fig. 1. It is quite evident that many of the yields were greatly increased by the lime. These soils might be grouped into three classes on the basis of their response to lime. The first class would include the three Norfolk and Cecil soils, the yields on all of these soils being increased directly with the amounts of Ca lime added. The second class would include the Kalmia soil in which the lime had no effect. The third class would include the two Decatur and the Hartsells soils in which the yields generally were increased only by the first increment of lime.

The Ca.Mg lime additions affected the yields differently in several soils as compared with the Ca lime. In the two Norfolk soils Nos. 940 and 942, and in Decatur soil No. 947, the yields were increased appreciably over the Ca lime applications. The Ca.Mg lime had about the same effect as the Ca on the yields of soils Nos. 941, 945, and 946. The results on the Cecil soil were different from those on all other soils in that the treatment equivalent to 50% saturation with Ca.Mg lime gave a higher yield than the same application of $CaCO_3$, while the 75% addition of Ca.Mg lime resulted in considerably lower yields than the same $CaCO_3$ applications.

The yields from the soils which were limed in the field indicated that the applications of lime were insufficient for maximum yields, except in soils Nos. 943, 945, and 947.

Growth of vetch, fourth crop.—The seeds were soil inoculated, and this crop was fertilized with 600 pounds per acre of a 6–10–12 fertilizer obtained from $(NH_4)_2SO_4$ and KH_2PO_4. This was the first P added since the first crop was planted. The yields of vetch are shown in Table 2. All of the soils except the Kalmia and the two Decatur soils gave a marked response to lime. The yields for the latter three soils were practically unaffected by lime, while the others reached a maximum at 75 to 100% saturation. The yields from the 50% Ca.Mg lime saturated soils were considerably higher than the Ca-saturated soils.

TABLE 2.—*Yields of vetch (fourth crop) grown in the greenhouse* *

Soil No.	Percentage Ca-sorption capacity								Field limed	Per cent increase 75 'N
	Native	Limed with $CaCO_3$					Ca.Mg			
		25	50	75	100	125	50	75		
940	3.75	4.95	6.60	9.15	10.1	7.75	8.15	7.65	3.75	244
941	4.45	5.95	7.50	8.25	8.80	8.35	7.75	——	5.80	195
942	4.20	4.20	6.55	7.70	7.55	7.65	7.15	8.75	5.90	183
943	3.50	——	6.10	8.55	8.70	7.05	8.10	8.65	7.50	244
945	7.75	——	9.15	9.40	9.65	9.00	9.90	——	9.65	121
946	7.25	——	6.95	7.20	8.10	7.70	8.25	7.70	7.60	99
947	8.05	——	7.80	7.40	8.15	7.75	7.30	——	——	92
948	1.00	5.20	6.90	7.80	7.00	6.85	7.85	8.60	——	780

*Grams per pot.

Growth of sorghum, fifth crop.—This crop was fertilized with 600 pounds of a 6–10–4 fertilizer. The yields were greatly increased by the lime (Table 3), in all soils except the Kalmia and Decatur soils, the highest yields resulting on the saturated soils with the exceptions noted.

Evidently much of the Ca and Mg had been removed by the four previous crops which accounts for the largest yield on the saturated soils. There was a tendency for the growth to increase at higher saturations with each succeeding crop, while that on the unlimed soils had decreased. A virtual failure of sorghum was obtained on the unlimed Cecil sandy loam.

TABLE 3.—*Yields of sorghum (fifth crop) grown in the greenhouse.**

Soil No.	Percentage Ca-sorption capacity								Field limed
	Native	Limed with $CaCO_3$					Ca.Mg		
		25	50	75	100	125	50	75	
940	18.7	18.8†	23.6	24.2	26.9	29.8	28.6	28.6	20.5
941	15.7	17.0	20.7	23.4	28.6	26.0	23.3	—	19.2
942	18.0	19.0	23.1	26.8	27.8	30.1	29.5	30.9	24.4‡
943	25.0	—	25.9	34.7†	36.2	30.1	34.2	33.3	33.8
945	32.7	—	36.4	34.7	34.8	36.4†	35.7	—	33.1
946	28.2	—	33.1†	36.2	33.5†	38.0	37.0	35.3	33.4‡
947	33.2	—	34.2	37.0	36.3	32.1	38.9	—	—
948	0.2	6.8	16.0	21.2	21.3	18.4	20.6	20.2	—

*Grams per pot
†Replicates do not agree.
‡Only one culture.

Growth of early Crotalaria spectabilis, sixth crop.—The soils were limed approximately 23 months previous to the planting of this crop. Similar fertilizers were supplied as for the preceding crop. The soils had become quite acid in the unlimed and lightly limed soils, as shown in Fig. 1 of the preceding paper (5). Satisfactory germination of the sacrified seed was obtained, but the seedlings began dying about 10 days after germination in the unlimed and low-limed soils with the exception of those on the two Decatur clay loams. The yields of crotalaria are recorded in Table 4 from which it may be seen that the crop failed on the light-textured soils at pH values below 5.0, but that satisfactory yields were obtained on the two Decatur soils at pH 4.80 and 4.95. The yields of crotalaria were directly related to the amounts of lime added up to the saturation point in all of the soils. The plants on the soils limed with $CaCO_3$ were chlorotic in all cases except on the Decatur soils. The chlorosis was typical of Mg deficiency and was not observed where Ca.Mg lime was added. It may

TABLE 4.—*Yields of crotalaria (sixth crop) as influenced by lime in the greenhouse.**

Soil No.	Percentage Ca-sorption capacity								Field limed
	Native	Limed with $CaCO_3$					Ca.Mg		
		25	50	75	100	125	50	75	
940	0	0	0	8.2†	18.2	12.1	12.5	15.2	0
941	0	0	4.0†	8.7	10.3	9.8	5.9†	—‡	0
942	0	0	0	7.0†	11.1	10.9	0	9.0†	—
943	0	—	5.5	14.4	20.0	17.8	6.8†	15.3	13.4
945	0.5†	—	4.1†	10.7†	13.8	12.8†	0.6	—	7.8
946	24.0	—	25.7	28.8	29.8	27.5†	27.4	28.7	26.5
947	24.7	—	26.8	27.6	27.3	24.9†	25.6	—	—
948	0	0	12.2	15.0	16.8	15.2	16.0	10.2	—

*Grams per pot.
†Duplicate pot yields do not agree
‡Not planted.

be seen also that the yields on all the soils except the Decatur soils were appreciably higher where Mg was applied.

Pertinent observations made during this study are that Mg became deficient on the light-textured soils more rapidly than Ca and that the more highly buffered and saturated soils promote growth at lower reactions.

EFFECT OF LIME ON PLANT COMPOSITION

The sorghum from the third crop was dried, ground, and analyzed for ash, total N, Ca, Mg, K, Mn, P, and Fe. Although analyses were

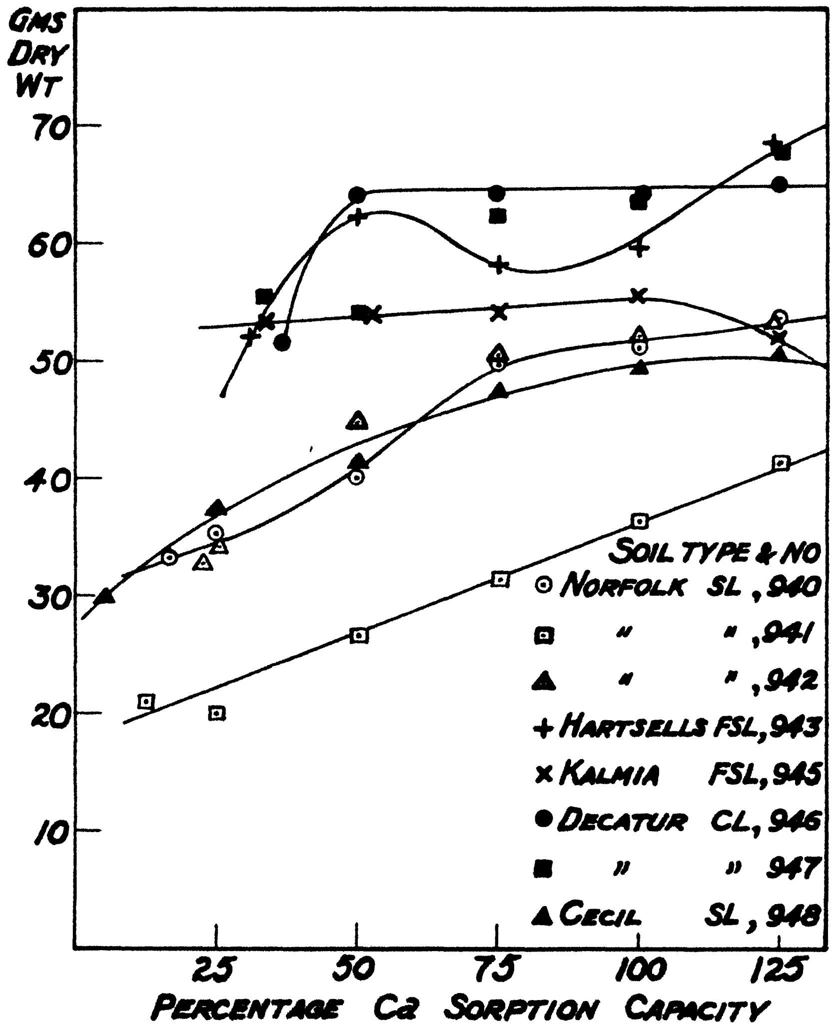

FIG. 1.—The influence of calcium saturation on the growth of sorghum, third crop.

made on crops from all of the soils, only those for the Norfolk soil No. 940, the Hartsells soil, and the Decatur soil No. 946 are given in Tables 5, 6, and 7, respectively. These data are typical of those obtained on both the light- and heavy-textured soils. For convenience, the effect of lime on each of the elements is discussed separately.

TABLE 5.—*Chemical composition of sorghum grown in greenhouse on Norfolk sandy loam (No. 940) limed for 1 year.*

Test No.	% saturation	Percentage of oven-dry weight							
		Ash	Total N	Ca	Mg	K	Mn	P	Fe
				Native					
1	—	3.75	0.515	0.80	0.26	0.35	0.034	0.105	0.025
				$CaCO_3$					
2	25	3.90	0.526	0.92	0.28	0.34	——	0.105	0.025
3	50	3.95	0.530	1.05	0.22	0.30	0.019	0.103	0.027
4	75	4.70	0.475	1.15	0.22	0.29	0.014	0.100	0.030
5	100	4.87	0.460	1.31	0.10	0.28	0.007	0.085	0.029
6	125	3.80	0.465	1.35	0.10	——	0.009	0.085	0.023
				$CaMg(CO_3)_2$					
7	50	3.95	0.510	0.54	0.54	0.28	0.013	0.105	0.022
8	75	3.75	0.500	0.42	0.70	0.15	0.009	0.125	0.018

TABLE 6.—*Chemical composition of sorghum grown in greenhouse on Hartsells sandy loam (No. 943) limed for 1 year.*

Test No.	% saturation	Percentage of oven-dry weight							
		Ash	Total N	Ca	Mg	K	Mn	P	Fe
				Native					
1	—	4.05	0.38	0.70	0.127	0.59	0.110	0.115	0.025
				$CaCO_3$					
2	50	3.55	0.40	0.80	0.135	0.48	0.075	0.082	0.022
3	75	4.08	0.38	0.98	0.111	0.48	0.088	0.075	0.025
4	100	4.28	0.42	1.22	0.092	0.48	0.050	0.075	0.016
5	125	4.15	0.38	1.28	0.067	0.39	0.050	0.058	0.016
				$CaMg(CO_3)_2$					
6	50	4.58	0.39	0.78	0.353	0.52	0.107	0.114	0.037
7	75	4.28	0.40	0.72	0.520	0.39	0.072	0.105	0.022
8	Field limed	4.13	0.38	0.70	0.483	0.46	0.053	0.100	0.025

Ash content.—A range of 4 to 6% in ash content was found on the different soils, the highest percentage being obtained on the lowest buffered soil. A high percentage of the ash consisted of Ca which increased directly with the amount of $CaCO_3$ added.

Nitrogen content.—The percentage of N in the plants varied from a minimum of about 0.4 to a maximum of about 0.8. The effect of the lime additions on the N of the plants was variable. Generally, where

TABLE 7.—*Chemical composition of sorghum grown in greenhouse on Decatur clay loam (No. 946) limed for 1 year.*

No.	% saturation	Per cent dry weight							
		Ash	Total N	Ca	Mg	K	Mn	P	Fe
				Native					
1	—	4.65	0.41	0.58	0.189	1.12	0.015	0.067	0.020
				$CaCO_3$					
2	50	4.70	0.36	0.62	0.195	1.15	0.014	0.067	0.020
3	75	4.25	0.38	0.66	0.172	1.05	0.012	0.058	0.020
4	100	4.25	0.45	0.74	0.160	0.96	0.012	0.032	0.020
5	125	4.40	0.44	0.78	0.158	0.90	0.012	0.050	0.020
				$CaMg(CO_3)_2$					
6	50	4.75	0.42	0.54	0.273	1.07	0.013	0.050	0.025
7	75	4.40	0.44	0.51	0.372	0.96	0.009	0.050	0.021
8	Field limed	3.95	0.46	0.60	0.220	0.72	0.009	0.045	0.020

the added lime increased the yield considerably, mostly on light-textured soils, the N content of the plants increased slightly and then decreased somewhat in the larger yields resulting from higher lime applications. It is quite likely that the N level of the soils was insufficient for the large increase in growth. The plants on the heavy-textured soils were either unaffected or inconsistent in their N content.

Calcium content.—The percentage of Ca in the sorghum plants was increased very greatly by the added $CaCO_3$, but it decreased slightly where the Ca.Mg lime was added as compared with the unlimed soils. These results are consistent and definite throughout all of the soils. In the 100% and 125% saturated soils, it might be said that there was "luxury consumption" of Ca by the plants. It is quite evident from these data that the buffer capacity of the soil influenced the absorption of Ca which was independent of the total exchangeable Ca in the soils; that is, in the Decatur soils, the percentage Ca in the plants was considerably lower than that of the plants grown on the other soils even though there was more exchangeable Ca in the former. The significance of this may be seen later in the general discussion of the effect of lime on other nutrients.

Magnesium content.—Liming soils with calcic lime has a reciprocal effect on the Mg content of plants grown on these soils. It may be seen from these data that the percentage Mg was quite low in the plants from the high Ca-saturated soils, and probably the plants were deficient in this element except on the Kalmia and Decatur soils. In the latter soils the plants had only a slightly lower content of Mg in the 100% and 125% Ca-saturated soils than at the lower saturations. The plants from the soils limed with Ca.Mg additions had a much higher content of Mg than those from the Ca-limed soils. Generally there were about equal percentages of Ca and Mg in the plants where Ca.Mg lime was added to the soils.

Potassium content.—The K content of plants decreased slightly

with the degree of saturation with Ca lime. The percentage K in the plants from the Ca.Mg applications was practically the same as that from the Ca applications. It was found in the preceding investigation (5) that the exchangeable K was much higher in the Ca.Mg-treated soils than in the Ca soils. It is difficult to explain the above K relationship and further investigation is needed on this problem.

Phosphorus content.—The percentage P in the plants grown on the soil without lime applications varied from 0.20% on the Norfolk soil to 0.05% on the Decatur soil. This same relationship was shown in the soil analyses (5). The Ca lime applications decreased the percentages of P in the plants of the light-textured soils, Nos. 940 to 943, inclusive, but had considerably less effect on the plants from the other soils. The Ca.Mg-limed soils produced sorghum which generally had slightly higher contents of P than the corresponding plants of the Ca-limed soils. However, there was only a slight difference in the readily available P of the soils limed with the materials from the two sources (5). These data indicate that there was slightly greater sorption of P by the plants from the Ca.Mg than from the Ca-limed soils.

Manganese content.—Liming the soils reduced the Mn content of the plants directly with the amount of lime added. In the highly Ca-saturated soils there was scarcely more than a trace of Mn present in the plants, which quite likely was insufficient for normal nutrition.

Iron content.—The percentage Fe decreased directly with the amount of lime added to the soils. It should be stated that the amounts of Fe are relative only as the method of analysis was not known to be highly accurate. It appears, however, that the Fe in the plants was not decreased by liming to the extent that the plants suffered from a lack of this element.

DISCUSSION

Greenhouse pot experiments have certain inherent limitations, such as change in structure of the soil when it is removed from its profile, non-adaptability of certain field crops such as corn and cotton to greenhouse growth, an increase in number of plants to quantity of soil, and the necessity of adding large amounts of fertilizers which affect the soil composition. However, an attempt was made to minimize these limitations during this investigation, and with proper interpretations the results are valuble to the study of the problem. Crops were selected which were known to make normal growth in the greenhouse and also which would give a response to lime typical of the general crops of the State.

The effect of lime on the growth of five successive crops in the greenhouse is shown graphically in Fig. 2. The first four crops of peas, rape, sorghum, and vetch are believed to represent the response of these crops to the amounts of lime added on a relatively poorly buffered light-textured soil. The soil acidity had increased after the fourth crop to the extent that the growth of the later crops must be interpreted in the light of the changes in soil reaction. This is shown by the yield curves of the sorghum from the third and fifth crops, the latter being a straight line function of the soil reaction.

The growth of the greenhouse crops on the Kalmia and Decatur soils was only slightly affected by the lime and data from an unpublished report show that this was also true for these crops in the field experiments conducted on these soils.

The chemical composition of plants was affected by soil type as well as by the amount and kind of liming materials used. From the

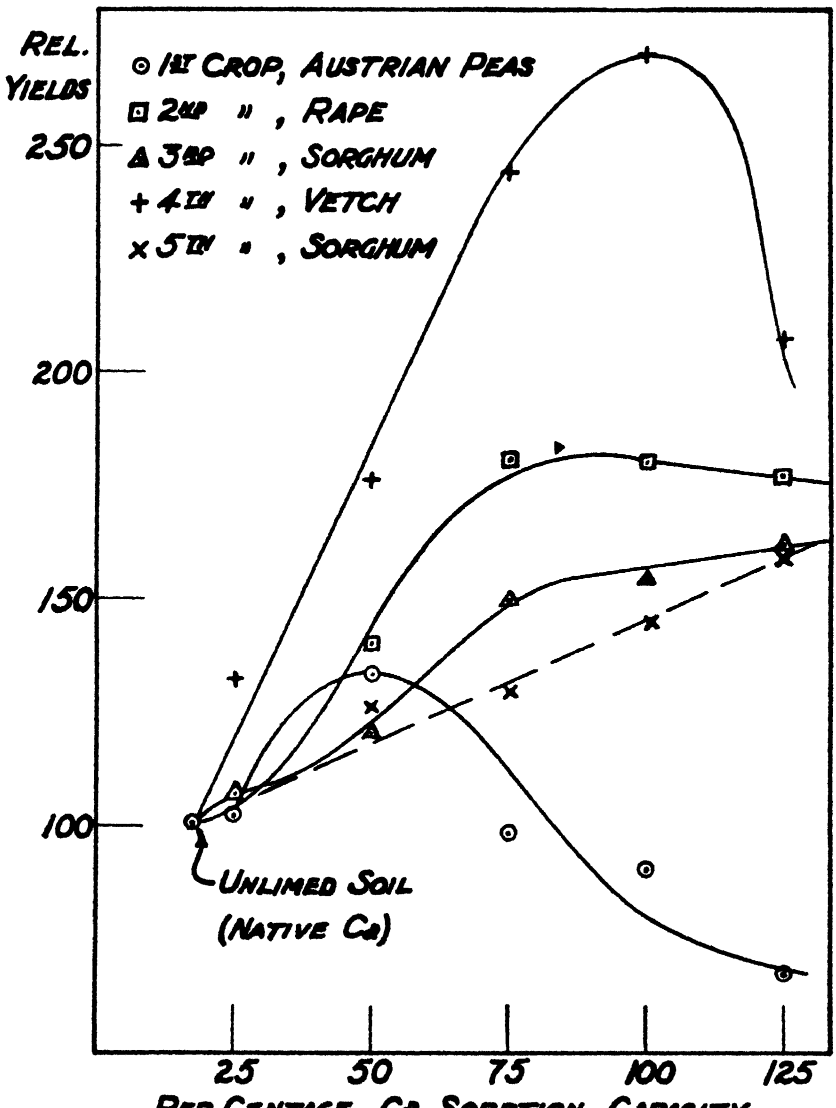

FIG. 2.—The effect of lime on successive crops in the greenhouse on Norfolk sandy loam, No. 940.

data on plant analyses the content of Ca, Mg, and Mn stand out as the constituents most affected. Quite likely the growth of plants was inhibited by an excess Ca absorption and low Mg and Mn availability or absorption in the light-textured soils where $CaCO_3$ was added to the soils. The influence on the clay loams was much less drastic (Table 7). The content of K in the plants on the Norfolk and Hartsells soils was considerably lower than that of the plants on the Decatur soils, but the reverse was true for P content. Analogous to this, the content of exchangeable K in the light-textured soils was much lower than that in the Decatur soils (5), whereas P was fixed more readily in the latter soils.

A detailed study was made of the effect of lime on the absorption of P and K by the plants on the different soils (Table 8). It would seem that these values, total amounts of P or K removed from the soil, are true measures of the availability of these ions providing there were no other limiting factors. The total P removed was increased by the addition of $CaCO_3$ on the Norfolk soil, decreased on the Hartsells soil, and was little affected on the Decatur soils. The addition of Ca.Mg lime greatly enhanced the utilization of P on the two light-textured soils. The total K removed by plants was increased by the Ca lime additions on the Norfolk and Decatur soils but was decreased slightly on the Hartsells soil. Additions of Ca.Mg lime generally decreased the removal of K by the plants even though the exchangeable K of the soil was greatly increased by these treatments.

TABLE 8.—*The influence of lime on the availability* of phosphorus and potassium to sorghum on different soils.*

Soil type†	Soil No.	Percentage Ca-sorption capacity and source of lime							
		Native	$CaCO_3$					Ca.Mg	
			25	50	75	100	125	50	75
				P (Grams x 10)					
Norfolk SL	940	3.47	3.70	4.13	4.95	4.33	4.75	4.71	6.88
Hartsells FSL	943	5.98	—	5.11	4.36	4.47	4.03	7.41	6.76
Decatur CL	946	3.45	—	4.28	3.70	2.04	3.24	3.02	3.04
				K (Grams)					
Norfolk SL	940	1.15	1.20	1.20	1.43	1.43	—	1.25	0.82
Hartsells FSL	943	3.07	—	2.99	2.80	2.86	2.64	3.38	2.50
Decatur CL	946	5.15	—	7.35	6.70	6.13	5.85	6.48	5.85

*(% P or K) (grams dry weight)
†SL = sandy loam; FSL = fine sandy loam; CL = clay loam.

In the present investigation over-liming was observed on Austrian winter peas, vetch, and to a slight extent on crotalaria, but was not noted on rape and sorghum. Where the injury occurred, soil reaction was above pH 6.5 and the injury was most serious on the light-textured soils. Therefore, when liming these soils for the more common soil improvement crops, such as peas, vetch, and crotalaria, care should be taken not to over-lime. On the other hand, sorghum, which is grown extensively for both syrup and forage, appears not to be

readily susceptible to over-liming. As a corollary to this, sorghum is known to produce heavy yields on Sumter clay, a highly calcareous soil of the Black Belt of Alabama.

SUMMARY

In a study of the influence of lime on the growth and composition of plants, six successive crops were grown in the greenhouse and the plants from one of the crops were analysed. This investigation included studies of kinds of lime, both $CaCO_3$ and $CaMg(CO_3)_2$, amounts of lime, different degrees of saturation, and soil type as they affect the growth and composition of plants. The results may be briefly summarized as follows:

1. Crop yields were increased on the Norfolk, Hartsells, and Cecil series of soils by liming. The third increment of lime, equivalent to 75% of the Ca-sorption capacity of the soils, was generally found to be the optimum rate of liming on these soils. The crops used gave little response to lime on the Decatur and Kalmia soils since these soils in their native states are highly saturated with bases.
2. A greater growth response was obtained from Ca.Mg lime than from Ca lime. This was especially true for the last two crops grown on the lighter-textured soils.
3. Liming with increasing increments of $CaCO_3$ increased the percentage Ca in the plants but decreased the Mg, K, P, Mn, and Fe. This was especially true on the light-textured soils and to the extent that certain mineral constituents of the crops were considerably decreased. Where the soils were limed with $CaMg(CO_3)_2$, there were similar decreases in mineral content, with the exception of Mg which was increased.

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GERMINATION OF SEEDS FROM CERTAIN SPECIES OF PASPALUM[1]

C. B. RAY AND RALPH T. STEWART[2]

THE genus Paspalum includes several valuable southern pasture and soil-binding grasses. *Paspalum dilatatum*, dallis grass, is the species most widely known and its seeds have been used in many pasture seeding experiments. Other species concerning which less is known, but which according to Chase[3] have pasture value, are *P. circulare*, *P. pubescens*, *P. boscianum*, *P. urvillei*, *P. notatum*, *P. vaginatum*, *P. distichum*, and *P. repens*.

Despite the wide distribution of the Paspalums in the South and their recognized value in pastures, none of the species have become generally used in pasture mixtures. Dallis grass, the most important species, is objected to because its seeds are expensive and when planted they seldom produce satisfactory stands.

Just why good stands of dallis grass are so difficult to procure in pastures has never been satisfactorily explained. Several writers have advanced the theory that viable seeds are seldom produced especially in the United States. Such an explanation, however, can hardly be justified in many areas. Dallis grass, because of its coarse, tussocky habit of growth is undesirable in lawns and parks, yet it is well known that the species often becomes a serious pest in such places. Since the plant does not propagate itself by stolons or rootstocks, it occurred to the authors that considerable quantities of viable seeds are produced, otherwise the species could not spread so rapidly in places where it is not wanted.

A review of the literature reveals no record of any extensive study having been made to determine the quality of Paspalum seeds produced in this country. However, because of the difficulty experienced in securing stands, there is a prevailing belief that they are low in viability. To obtain definite information on the quality of Paspalum seeds, samples from a number of species were collected from various localities and tested for germination. Seeds were also purchased from a number of recognized seed firms in order to determine the quality of available commercial seed stocks and to compare their germination with the germination of samples collected in Texas.

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[1]Contribution from the Department of Agronomy, Agricultural and Mechanical College of Texas, College Station, Texas. This paper is an abstract of a thesis submitted by the senior author to the Graduate Faculty in partial fulfillment of the requirement for the degree of master of science and its publication is authorized by the Head of the Agronomy Department. Received for publication March 23, 1937.

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[3]CHASE, AGNES. The North American Species of Paspalum. U. S. Nat. Mus. Contr., U. S. Nat. Herb., Vol. 10, Part 2. 1929.

MATERIALS AND METHODS

Since several species of Paspalum are being grown at a number of sub-stations of the Texas Agricultural Experiment Station, it was convenient to secure seeds from those sources.[4] Other samples were collected from widely scattered areas in Texas and from a number of commercial seed firms located in the South. In all, 16 samples of seeds were secured from the Texas Agricultural Experiment Station sub-stations, 10 from other regions of Texas, and 5 from commercial seed houses.

The experiments were started during the fall of 1935. Before making germination tests each sample was examined to determine the percentage of seeds damaged by ergot, *Claviceps paspali*, a fungous disease attacking the developing embryo, and the percentage of seeds containing normal embryos.

Preliminary germination tests with commercial seeds were started during December 1935. One hundred seeds were placed on moist paper towels in unglazed dinner plates. To prevent rapid drying, each plate was placed in a pan of water and a second plate inverted over it. Duplicate tests were also made in a Sho-Gro germinator[5], the seeds being placed on moist paper towels and kept over a pan of water. The temperature range for this test was kept between 25° and 26° C. To check the methods, germination tests were also made using seeds of red clover, meadow fescue, and timothy.

As the percentage germination of the dallis grass seeds by the above methods was much less than for the seeds used as a check, it was decided to repeat the test with the temperature raised to 30° C. For this test the seeds were placed on moist paper towels in covered petri dishes and kept in the Sho-Gro germinator. A small piece of wood was inverted in the cover of each petri dish to permit free air circulation over the seeds.

Quicker germination of the dallis grass seeds was obtained in the second preliminary test than in the first. At 30° C the seeds germinated in 4 days, while 25 days were required for seeds of the same sample to germinate at a temperature of 25° C. It was decided, therefore, to make all future germination tests of dallis grass seeds at temperatures between 30° and 32° C.

RESULTS

In Table 1 are shown the results with dallis grass seeds obtained from various sources and tested as in the second preliminary test with the temperature held at 30° C.

The data in Table 1 show that ergot infection was less and germination higher in commercial lots of dallis grass seed than in the samples collected in Texas. Some of the difference between the germination of commercial seeds and seeds collected in Texas is easily accounted for by the fact that in the commercial seeds more of the spikelets contained a caryopsis. The higher per cent of ergot infection in Texas seeds did not appear to reduce their germination. In the commercial seeds, however, sample No. 13 containing 12% ergot infection, showed the poorest germination.

It is also interesting to note that the dallis grass seeds, sample No.

[4]The seeds from the sub-stations of the Texas Agricultural Experiment Station were furnished to the authors by Dr. E. B. Reynolds, Chief of the Agronomy Division of the Experiment Station, and his assistants.

[5]A seed germinator sold by the Seed Trade Reporting Bureau, 325 West Huron Street, Chicago, Ill.

TABLE 1.—*Germination of seeds and ergot infection in samples of Paspalum dilatatum seeds obtained from various sources.*

No. of sample*	Source of seed	Ergot infection, %	Spikelets containing Caryopses, %	Caryopses germinating, %	Spikelets germinating, %
1	Bryan, Texas	0	0	0.0	0.0
2	Bryan, Texas	0	0	0.0	0.0
3	Bryan, Texas	20	20	0.0	0.0
4	Navasota, Texas	40	19	15.8	3.1
5	Nacogdoches, Texas	36	6	8.3	0.5
6	Tyler, Texas	0	25	0.0	0.0
7	Tyler, Texas	0	25	0.0	0.0
8	Tyler, Texas	0	25	0.0	0.0
9	Commercial seed	0	25	12.0	3.0
10	Commercial seed	0	33	33.3	11.0
11	Commercial seed	0	45	40.0	18.0
12	Commercial seed	0	45	17.8	8.0
13	Commercial seed	12	15	11.5	1.7
14	Commercial seed	0	34	23.2	7.9

*Seeds in samples No. 9 and 10 were purchased from the same commercial seed company Sample No. 9 was purchased during 1934 and tested in 1935. All other samples were collected or purchased during 1935.

9, purchased in 1934 and tested in 1935 gave only 3% germination, while seeds purchased from the same company in 1935, sample No. 10, gave 11% germination.

In Table 2 are shown the results obtained from germination tests of seeds from Paspalum species other than *dilatatum*. The data reported were obtained from tests using the same method and temperature as employed in securing the data in Table 1. Because of the poor

TABLE 2.—*Germination of seeds and ergot infection in samples of Paspalum species other than dilatatum collected during 1935 from various points in Texas and tested for germination without previous seed treatment.*

No. of sample	Source of seed	Species	Ergot infection %	Spikelets containing caryopses, %	Caryopses germinating, %	Spikelets germinating, %
1	Bryan	*floridanum*	0	8	0.0	0.0
2	Bryan	*floridanum*	0	58	0.0	0.0
3	Bryan	*floridanum*	0	36	0.0	0.0
4	Bryan	*plicatulum*	2	23	0.0	0.0
5	Nacogdoches	*urvillei*	0	36	0.0	0.0
6	Nacogdoches	*urvillei*	0	28	0.0	0.0
7	Nacogdoches	*notatum*	0	30	0.0	0.0
8	Moody	*distichum*	0	54	0.0	0.0
9	Lufkin	*notatum*	0	24	0.0	0.0
10	Fairland	*floridanum*	0	0	0.0	0.0
11	Angleton	*lividum*	0	5	0.0	0.0
12	Angleton	*almum*	0	11	0.0	0.0
13	Angleton	*urvillei*	0	5	0.0	0.0
14	Angleton	*floridanum*	0	35	0.0	0.0
15	Angleton	*notatum*	0	30	0.0	0.0
16	Tyler	*notatum*	0	6	0.0	0.0
17	Tyler	*virgatum*	0	5	0.0	0.0
18	Tyler	*lividum*	0	6	0.0	0.0

results checks were made during March on each of the samples as follows: One in the Agronomy Department greenhouse, one in the Sho-Gro germinator at 25° C, one in the Sho-Gro germinator at 32° C, and one in moist sand under outside conditions. Regardless of method or temperature used none of the seeds germinated.

Table 2 indicates that ergot infection in species of Paspalum other than dallis grass was not common in Texas during 1935. Whether this phenomenon is generally true from year to year remains to be determined. The data also indicate that the percentage of spikelets containing a caryopsis was not materially different from that of dallis grass.

During the latter part of May, the hot days and cool nights made it difficult to regulate temperatures in the various germinators being used. For subsequent tests a General Electric refrigerator equipped with a thermostat was secured and regulated to a constant temperature of 32° C.

In June 1936, seeds of the current crop of Paspalum were collected for testing. Before being placed in the germinator, samples of the dallis grass seeds were subjected to temperatures of 10° C and —6.7° C for periods ranging from 1 to 20 days. Others were treated with 37% hydrochloric acid (commercial) for periods ranging from 30 seconds to 60 minutes. Tests were also made with seeds after removing the lemma and palea from their caryopses and with still other seeds after puncturing their lemmas or paleas with a needle.

Results obtained from the various attempts to increase the germination of seeds of Paspalum species are shown in Tables 3 and 4. Table 3 shows that dry seeds subjected to temperatures of 10° and — 6.7° C for 20 days before being tested germinated 2.0% while seeds exposed to these temperatures for shorter periods did not germinate. Wet seeds, however, were not benefitted by temperature variation.

Dallis grass seeds treated with 37% hydrochloric acid for 0.5-, 2-, and 60-minute periods failed to germinate. However, seeds treated for 1, 3, 5 and 10 minutes gave germination percentages of 2.0, 4.9, 10.8, and 5.9, respectively.

The greatest increase in the germination, however, resulted from removing the lemma and palea from the caryopses. In this test 33.5% of the seeds germinated. By puncturing the lemma and palea to permit moisture to reach the kernel 18.8% of the seeds were made to germinate.

Table 4 shows that spikelets of *P. floridanum* and *P. publiflorum* containing caryopses which failed to germinate when tested by ordinary methods germinated 58% and 78%, respectively, when their lemmas and paleas were removed from their caryopses.

DISCUSSION

It was stated earlier in this paper that species of Paspalum are recognized as valuable pasture and soil-binding plants. Their use, however, has been restricted because of the extreme difficulty encountered in trying to secure stands by planting their seeds. On the other hand, dallis grass, the most important species, becomes a pest in lawns and parks where it is not wanted.

TABLE 3.—*The effect of certain treatments upon the germination of dallis grass seeds.*

Treatment	Spikelets containing caryopses, %	Caryopses germinating, %	Spikelets germinating, %
No treatment	47	0.0	0.0
1 day at 10° C (dry)	47	0.0	0.0
3 days at 10° C (dry)	47	0.0	0.0
5 days at 10° C (dry)	47	0.0	0.0
7 days at 10° C (dry)	47	0.0	0.0
20 days at 10° C (dry)	47	4.3	2.0
1 day at −6.7° C (dry)	47	0.0	0.0
3 days at −6.7° C (dry)	47	0.0	0.0
5 days at −6.7° C (dry)	47	0.0	0.0
7 days at −6.7° C (dry)	47	0.0	0.0
20 days at −6.7° C (dry)	47	4.3	2.0
1 day at −6.7° C (wet)	47	0.0	0.0
3 days at −6.7° C (wet)	47	0.0	0.0
5 days at −6.7° C (wet)	47	0.0	0.0
7 days at −6.7° C (wet)	47	0.0	0.0
20 days at −6.7° C (wet)	47	0.0	0.0
HCl for 30 seconds	47	0.0	0.0
HCl for 1 minute	47	4.3	2.0
HCl for 2 minutes	47	0.0	0.0
HCl for 3 minutes	47	10.4	4.9
HCl for 5 minutes	47	22.9	10.8
HCl for 10 minutes	47	12.5	5.9
HCl for 60 minutes	47	0.0	0.0
Lemma and palea punctured	47	40.0	18.8
Lemma and palea removed	47	92.5	33.5
Lemma and palea removed*	45	24.0	10.8

*Seeds used in this test were taken from the same lot of seeds as sample No. 11, Table 1.

TABLE 4.—*Showing the effect upon the germination of Paspalum floridanum and P. pubiflorum seeds when the lemmas and paleas were removed.*

Species	Treatment	Caryopses germinating, %
floridanum	Check	0.0
floridanum	Treated	58.0
pubiflorum	Check	0.0
pubiflorum	Treated	78.0

These experiments, while not extensive, seem to help explain this unusual phenomenon. Samples of dallis grass seeds collected in the fall of 1935 failed to germinate in April 1936 without receiving artificial treatment regardless of method or environment. Commercial seeds that had shown 18% germination in January 1936 germinated only 1% in April. Out of 3,500 seeds of the 1935 crops tested during

April only 6 germinated. The same samples of seeds were again tested in June giving 0% germination. There was nothing in the methods of germination to which these peculiar and unexpected results could be attributed. Naturally it was suspected that the 1935 seeds had lost all or at least a large part of their viability by April 1936. The results obtained from the 1934 and 1935 commercial lots, samples No. 9 and No. 10, also contributed to such a conclusion. An examination of the spikelets containing a caryopsis which did not germinate in the April tests revealed that their kernels had rotted which further indicated that viability in the seeds had been materially reduced by age.

The discouraging results obtained from the germination tests with the 1935 seeds caused the authors to discontinue for a time their work with old seeds and concentrate their efforts upon dallis grass seeds produced in 1936. During June a considerable supply of dallis grass seeds was collected from the vicinity of College Station, Texas, and tested for germination. As shown in Table 3, ordinary germination tests without seed treatment produced no better results than had been obtained from tests with the 1935 seeds.

The only alternative seemed to be to try some kind of artificial seed treatment. With this thought in mind the various methods shown in Table 3 were tried. The data indicate that if dry seeds are exposed to low temperatures for several days their germination may improve. Exposing wet seeds to low temperatures did not effect their germination.

Treating the seeds with 37% hydrochloric acid for 3 minutes and no longer than 10 minutes slightly increased their germination. The lemma and palea of seeds treated with acid for periods less than 3 minutes were either little affected or became more or less tough and leathery depending upon the length of treatment. Seeds treated longer than 10 minutes were almost completely decomposed. These results indicate that properly conducted acid treatments will increase the germination of dallis grass seeds and that the optimum length of treatment with 37% hydrochloric acid is somewhere between 5 and 10 minutes.

The final attempt to increase the germination of dallis grass seeds was to remove the lemma and palea. This treatment gave excellent results, 33.5% of the seeds germinating. The next step was to try puncturing the lemma or palea with a needle which resulted in a 18.8% germination. These encouraging results prompted the authors to try removing the lemma and palea from the old 1935 commercial seeds, sample No. 11 which had given 18% germination in January, 1% germination in April, and 0% germination in June. As shown in Table 3, 10.8% of the seeds germinated in this test. Equally good or better results were obtained when the lemma and palea were removed from the seeds of *P. floridanum* and *P. publiflorum* before being tested for germination.

CONCLUSIONS

From these experiments it would seem that considerable viable seeds are produced by certain species of Paspalum. Several conditions may, however, prevent one from securing a satisfactory stand

when the seeds are planted. First, there is good evidence that the seeds deteriorate with age and that seeds more than 1 year old are less likely to grow. Second, moisture may not be able to enter through the lemma and palea in quantities sufficient to cause the seeds to sprout. On the other hand, enough moisture may penetrate the hulls to cause the seeds to rot. A third condition likely to contribute toward a poor stand is that moisture may not penetrate through the lemma and palea until the seeds have remained on the ground for a considerable time. When the seeds do finally germinate dry hot summer weather may kill the seedlings or weeds smother them before they become established.

To what extent the above conditions influence the establishment of stands of Paspalum species in pastures has not been determined. It is important, however, to remember that in lawns and parks where dallis grass establishes itself of its own accord conditions are more favorable to seedling growth than in the average farm pasture. There the soil is fertile, the weeds are kept down and moisture is more plentiful.

The poor germination obtained from old seeds and the high germination obtained from seeds treated in such a way as to permit moisture to contact the kernel are good indications that only new seeds should be used and that some scarifying treatment to render the hull pervious to water should be given paspalum seeds before they are planted.

EFFECTS OF SELF-POLLINATION IN RAPE[1]

Von Gee Sun[2]

STANDARD methods of breeding have been developed for self-pollinated plants, but in the cross-pollinated group such standard procedure has been developed only with corn. Studies with rape, a frequently cross-pollinated crop belonging to the genus Brassica and which is grown extensively as an oil crop in central China, should help materially in developing a technic adapted to this group of crop plants.

Two questions naturally arise concerning breeding methods with rape, *viz.*, (a) Is it possible to obtain an adequate amount of selfed seeds from rape plants by means of controlled self pollination and what percentage of seed set can be secured, and (2) how much vigor is lost, if any, with successive generations of inbreeding? This paper will present some data bearing on these questions.

LITERATURE REVIEW

As a rule, in different species of the cabbage group, cross pollination has been found usually to be more efficient than self pollination. This greater efficiency of cross as compared with self pollination was recognized very early. Roemer (6)[3] mixed pollen from green and red cabbage plants and applied it to the stigmas of emasculated flowers of the green parent. Since red is dominant over green, all crossed seed should result in red plants. Upon germinating the seed he secured a preponderance of red plants, i.e., 137 red to 29 green instead of the expected ratio of 84 to 84 green plants.

A similar test was made by Pearson (5) at Davis, Calif. Pollen was placed on the stigma of the same plant during the morning when the flowers opened and immediately afterward pollen from a commercial, red cabbage plant was applied to the same stigmas. Of the 907 seeds which germinated, only 53 gave rise to green plants. These obviously arose from self pollination. Apparently foreign pollen was favored over pollen from the same plant.

Kakizaki and Kasai (3) studied the mode of pollination in *Brassica pekinensis* Rupr. and *Raphanus sativus* L. Their results showed that by bud pollination the amount of selfed seed obtainable was notably increased, especially when the plants were highly self-incompatible.

Kakizaki (2) stated that self- and cross-incompatibility in cabbage is caused by the slow rate of pollen tube growth. This slow rate of growth when incompatible pollen was used is due primarily to the presence of a substance which inhibits the growth of the pollen tube in the stylar tissue. The normal growth of pollen tube

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[3]Figures in parenthesis refer to "Literature Cited", p. 566.

of compatible pollen is a result of either the absence of such an inhibiting substance or the presence of as accelerating substance which is able to prevent the inhibiting action. Genetically, the rate of pollen tube growth is controlled by two contradictory allelomorphic series, one oppositional S_1, S_2, and S_3 and the other sympathetic T_1 and T_2, the S series being epistatic over the T series, but the T in the homozygous condition inhibits S when heterozygous.

Pearson (5) showed that self pollination was as effective as cross pollination if applied at the proper time. The stigma is receptive to pollen for about five days betore the flowers open and until four days after. If sufficient time is given the pollen tubes to reach the ovules, selfed seed can be obtained rather easily.

Stout (7), working on *Brassica pekinensis*, stated that selection for a high degree of seed setting with self pollination was carried out for seven generations during which time no entirely self-fertile line was isolated. A period of self fertilization occurred in the middle of the flowering period. In the periods of incompatibility very few of the pollen tubes entered the style, many of these remaining coiled on the papillae. The coiling was not observed in the mid-period of compatibility during which time a number of pollen tubes passed through the style into the ovary.

Akhtar (1) conducted some pollination studies with the Indian species of Brassica. His results showed that some species were self sterile while others were self fertile. Experiments with *Brassica campestris* L. var. *oleifera* Prain showed that the greatest amount of seed was obtained when the flowers were pollinated to two days before opening. Investigations on the rate of pollen tube growth showed that the pollen germinated in all cases but that the growth of foreign pollen was the most rapid, requiring 5 hours to effect fertilization, while pollen from the same plant took 24 hours to effect fertilization. Consequently, if pollen was applied one to two days before the flowers opened, fertilization was accomplished. This agrees entirely with Pearson's and Kakizaki's results.

Mohammad (4) stated that the floral mechanism in *Brassica napus* L. var. *dichotoma* Prain and *B. campestris* L. var. *sarson* Prain does not favor self pollination. Cross pollination is the rule in these species with the exception of a yellow-seeded sarson form in which considerable self pollination takes place. The insects mainly concerned in affecting cross pollination are *Adrena ilerda*, *Apis florea*, and *Halictus sp.* Mohammad concluded that if self-sterility is due to secretion of a substance which inhibits the growth of the pollen tubes when the plant's own pollen is used, then the substance must be secreted only one to two days before the flowers open. The stigmas remain fully, or nearly fully, receptive for about three days, after which there is a decline in fertility. After five days hardly any pod setting or seed formation was obtained. The pollen remained viable for a period of seven days or more after collection from freshly opened flowers. Mohammad found that inbreeding resulted in a decrease of vigor and yield, and recommended mass selection as a means of improving the crop. In the case of the yellow-seeded, self-fertile form of sarson, however, several types, some of which seemed very promising, were isolated from the ordinary mixed variety by inbreeding.

MATERIALS AND METHODS

In 1933, 51 individual plants of rape were selected at random from a mixed population in a farmer's field in Hangchow, China. These plants were classified into two groups according to seed color, i.e., yellow and red. Plant rows from these 51 plants were grown at Wusih in the period from October 1933 to June 1934. During the blossoming time from March to May 1934 one or more inflorescences from

selected plants were bagged with 4 x 14 inch glassine bags in order to avoid cross pollination. The bags were raised every day in order to prevent the rapidly elongating inflorescences from turning around within the bags.

Fifty-seven such bagged inflorescences were harvested and the number of matured siliques, number of flower peduncles, number of ovules, and number of matured seeds per inflorescence were recorded. The number of ovules per inflorescence was determined on the basis of the number of small scars which could be identified through examination of the placenta of the developed or undeveloped pod. In order to compare the percentage of seed set between open- and self-pollinated inflorescences on the same plants, the above-mentioned four characters were noted on an open-pollinated inflorescence selected at random from each of the same 57 plants. In addition, height of plants, number of inflorescences, and yield of seed in grams were determined for the plants which bore the bagged inflorescences.

In the yellow-seeded group, 32 out of 204 plants had red instead of yellow seeds. It may be probable that these 32 plants were the result of natural crosses between yellow- and red-seeded plants in 1933 before the selections were made for this study.

One lot of self- and one of open-pollinated seeds from each of the 57 plants bagged in 1934 were sown in pots on October 9 and transplanted to the field on November 30, 1934. Plants from open- and self-pollinated seed belonging to the same line were grown side by side in the field at the College of Agriculture of the National Central University, Nanking, China, in order to compare the yielding ability of these open- and self-pollinated progenies within the same line. The entire experiment consists of 102 rows, each row containing 30 plants. The rows were 5 metres in length and spaced 2/3 metre apart. On account of several heavy frosts immediately after transplanting, the seedlings in the majority of rows were killed. The survival was low, ranging from 0 to 33% per row. Since it was impossible to obtain plat yield data with such a reduced stand, only single plant studies were made. In this experiment the plant characters considered were height of plants, number of inflorescences per plant, yield of seed in grams per plant, size of seed, seed color, and date of maturity.

EXPERIMENTAL RESULTS

EFFECTS OF SELF POLLINATION ON SEED SET

The percentage of seed set from the self-pollinated inflorescences in 1934 varied from 5.8 to 51.0, the average being 21.46. The percentage of seed set in the open-pollinated inflorescences on the same plants varied from 26.4 to 88.4, the average being 63.03. The significance of the difference between the percentage of seed set in the different lines and between the two methods of pollination was tested by means of an analysis of variance. The calculations for the analysis of variance are given in Table 1.

The observed value of F for a comparison of seed set in both self- and open-pollinated inflorescences on the same plants was 2.00 and exceeds the 1% point. It is apparent, therefore, that the total amount of seed obtained from each line by both methods of pollination was significantly different in different lines.

Comparing the variance for amount of seed set by self vs. open pollination with the error variance leads to an observed F value of

TABLE 1.—*Analysis of variance of percentage of seed set in open- and self-pollinated inflorescences on the same plants of rape in 1934.*

Variation due to	D. F.	Sums of squares	Mean squares	Observed F	1% point of F
Lines	56	12724.77	227.23	2.00	1.87
Method of pollination.	1	49246.11	49246.11	434.21	7.12
Error.	56	6351.20	113.41	—	—
Total	113	68322.08			

434.21. This is highly significant, indicating that the probability of obtaining such a result as a consequence of random sampling is very remote. The variance (mean square) for a single plant was 113.41%, the standard error of the difference between the means of open- and self-pollinated inflorescences on all lines would be $\sqrt{\frac{113.41}{57}} \times \sqrt{2} = 1.99\%$. The difference between the two means was 41.57%. The difference is highly significant, a conclusion reached also by considering the observed value of F.

In 1935, only 20 pairs of open- and self-pollinated inflorescences were studied. The percentage of seed set when self-pollinated varied from 6.7 to 42.1, with an average of 23.74. The seeds set on the open-pollinated inflorescences ranged from 57.2 to 89.0%, with an average of 71.47%. The same method of analysis as described above was employed. The analysis is given in Table 2.

TABLE 2.—*Analysis of variance of percentage of seed set on an open- and self-pollinated inflorescences on the same plants of rape in 1935.*

Variation due to	D. F.	Sums of squares	Mean squares	Observed F	1% point of F
Line.	19	2979.44	156.81	1.29	3.08
Method of pollination	1	22781.53	22781.53	187.99	8.18
Error	19	2302.45	121.18	—	—
Total.	39	28063.42			

The observed value of F for comparing the variance between lines with error variance was not significant. The mean difference between open- and self-pollinated inflorescences was highly significant, however, since the observed value of F for comparing the mean square due to method of pollination with error very greatly exceeded the expected value for the 1% point.

The analyses given in Tables 1 and 2 show clearly that the amount of seed obtained when the inflorescences are bagged to ensure self pollination is significantly reduced as compared with the seed obtained by open pollination. Even though the percentage of seed set in the bagged inflorescences is significantly reduced yet the amount of selfed seed set per inflorescence reached as high as 563 in 1934 and 348 in 1935 which are sufficient to enable one to continue inbreeding as a method of rape improvement.

EFFECT OF INBREEDING ON YIELD

As has been pointed out above, it was impossible to obtain plat yields in 1935 due to a killing frost at transplanting time. As a consequence it was necessary to work data from single plants.

In order to determine whether there was a relationship between yielding ability of the progenies of self- and open-pollinated seed, the data were analyzed by means of X^2 for independence. In Table 3 is given the distribution of the number of plants from open- or self-pollinated seed in different yield groups.

TABLE 3.—*Frequency distribution of plants from open- and self-pollinated seed in relation to yield of plants in grams.*

Yield per plant, grams	Number of plants		Total
	Open-pollinated	Self-pollinated	
0.1- 1.0	0	2	2
1.1- 2.0	0	1	1
2.1- 5.0	1	5	6
5.1-10.0	2	10	12
10.1-15.0	9	10	19
15.1-20.0	11	8	19
20.1-25.0	13	9	22
25.1-30.0	12	6	18
30.1-35.0	11	2	13
35.1-40.0	10	2	12
40.1-45.0	3	1	4
45.1-85.0	20	10	30
Total	92	66	158

It is seen that the distribution of yields of the open-pollinated progenies was markedly shifted in the direction of higher yields when compared with the selfed progenies.

Grouping the data in Table 3 as indicated in order to avoid the small frequencies at both ends of the distribution and applying a X^2 test for independence, $X^2 = 21.690$. For five degrees of freedom a X^2 value as large as the observed would occur less than once in 100 trials by errors of random sampling. It is apparent, therefore, that the yield of plants from self-pollinated seed was significantly lower than that from open-pollinated seed. This conclusion is in line with the results usually obtained from inbred lines of naturally cross-pollinated crops.

More critical comparisons of the effect of inbreeding could be made by comparing plants arising from self- and open-pollinated seed harvested from the same plants in 1934. The data for such a comparison are given in Table 4.

The analysis of the data from Table 4 presents some difficulties because of disproportionate frequencies. An approximate analysis may be made by working with the mean yields for each line. The analysis of variance, on this basis, is given in Table 5.

TABLE 4.—*Yield of plants from open- and self-pollinated seed obtained from the same plants the previous year.*

From open-pollinated seed			From self-pollinated seed		
1935 row No.	No. of plants	Mean yield per plant, grams	1935 row No.	No. of plants	Mean yield per plant, grams
11	6	28.6	12	1	49.0
13	3	48.9	14	8	18.7
23	7	40.5	24	3	30.8
35	4	34.2	36	2	11.0
39	4	37.0	40	1	24.0
43	3	47.3	44	5	15.4
49	2	44.0	50	1	3.5
53	1	23.0	54	3	42.8
59	1	54.0	60	6	43.4
67	3	26.7	68	4	19.1
75	2	34.0	76	1	0.2
85	1	18.0	86	4	12.0
87	1	28.0	88	2	9.5
91	10	17.3	92	2	10.0
95	1	31.2	96	1	19.7
101	5	35.0	102	1	7.0
Total	54	547.7		45	316.1
Mean		34.23			19.76

TABLE 5.—*Analysis of variance of yield of plants from open-pollinated and one-year inbred seed obtained from the same plants in 1934.*

Variation due to	D. F.	Sum of squares	Mean squares	Observed F	5% point of F
Lines	15	2741.21	182.75	1.22	2.48
Open vs. selfed seed	1	1676.20	1676.20	11.21	4.54
Error	15	2243.68	149.58	—	—
Total	31	6661.10			

Since the observed F for a comparison of the variance for lines with error failed to reach the 5% point, it may be concluded that the different lines were not significantly different in yielding ability.

The highly significant value of F for a comparison of plants from open- and self-pollinated seed indicates clearly that the means of these two groups were significantly different. The mean yield of the plants from open-pollinated seed (Table 4) was 34.23 grams, while the mean yield of plants from selfed seed was but 19.76 grams, a reduction of 42% in yield.

An even more critical test of the effects of one year of inbreeding on the yield of the resulting progeny would be provided by a comparison of pairs of plants grown in adjacent rows in the field, one row of plants arising from selfed seed and the other from open-pollinated seed. By such pairing of plants the effect of soil variability is reduced to a minimum. Fifteen such paired comparisons were available from the 1935 data. These are given in Table 6.

TABLE 6.—*Yield of paired plants from progenies of open- and self-pollinated seed obtained from the same parental plants in 1934 and grown in adjacent rows in 1935.*

Open pollinated in 1934		Self pollinated in 1934	
1935 row and plant No.	Yield, grams	1935 row and plant No.	Yield, grams
11—1	28 5	12—1	49.0
13—1	66.0	14—1	22.0
13—2	58 0	14—6	11.0
23—4	33 0	24—1	24.5
23—6	54.0	24—2	21.5
23—7	35 5	24—3	46.5
35—1	22.0	36—1	17.0
43—1	50.0	44—1	24.0
53—1	23 0	54—2	35.0
59—1	54.0	60—5	51.0
67—1	38.0	68—1	8.0
67—2	24 0	68—3	27.5
75—2	30.5	76—2	0.2
91—1	20.5	92—1	8 5
91—2	27.5	92—2	11.5
Sum	564.5		357.2
Mean	37 63		23.81

These data were analyzed by means of the analysis of variance and the results given in Table 7.

TABLE 7.—*Analysis of variance of yield of paired plants from open- and self-pollinated seed and grown side by side in the field.*

Variation due to	D. F.	Sum of squares	Mean squares	Observed F	5% point of F
Lines . . .	14	3532.55	252.32	—	—
Open vs. self . . .	1	1432 44	1432.44	6.65	4.6
Error. . .	14	3017.10	215.51	—	—
Total . .	29	7982.09			

Table 7 indicates that the variation due to effect of one year of selfing was significantly greater than the variation due to error. The observed mean difference between the mean yield of the plants from open- and self-pollinated seed was 13.82 grams. The reduction in yield as a result of one year of selfing could be considered highly significant. It may be concluded, therefore, that the plants from open-pollinated seed yielded far better than the plants from inbred seed. Inbreeding tended to decrease the yield of rape, the reduction in yield, in this comparison, being 37%. It must be remembered that these results are based on rather small samples. The comparison between open- and self-pollinated plants within the same lines, ignoring the actual location where the plants were grown, agrees fairly well.

EFFECT OF INBREEDING ON HEIGHT OF PLANTS

In Table 8 are given the frequencies of plants in different height groups arising from open- or self-pollinated seed.

TABLE 8.—*Frequency distribution of height of plants in relation to method of pollination the previous year.*

Height of plants, cms	Number of plants	
	Open-pollinated	Self-pollinated
40–60	10	8
61–70	17	15
71–80	27	20
81–90	24	14
91–130	14	9
Total	92	66

Grouping the plants into five groups regarding height and comparing with the number of plants in each group arising from open-self-pollinated seed by means of the X^2 test, leads to a value of X^2 or = .853, a non-significant value. On the basis of this comparison it can not be said that the height of the plants from open-pollinated seed was significantly different from the plants arising from inbred seed.

EFFECT OF INBREEDING ON NUMBER OF INFLORESCENCES PER PLANT

A study was made also of the effects of inbreeding on the number of inflorescences of the resulting plants. The data are given in Table 9.

TABLE 9.—*Frequency distribution of the number of inflorescences per plant in relation to method of pollination the previous year.*

Number of inflorescences per plant	Number of plants	
	Self-pollinated	Open-pollinated
6–15	11	5
16–20	6	15
21–25	9	14
26–30	13	14
31–35	10	21
36–40	7	10
41–70	10	13
Total	65	92

A X^2 test for independence applied to the data of Table 9, grouping the number of inflorescences into seven groups, gave a X^2 value of 7.993. The value of P would lie between 0.3 and 0.2, indicating no association between number of inflorescences per plant and method of pollination the previous year.

EFFECT OF INBREEDING ON SEED SIZE

In Table 10 is given the frequency distribution of the weight of 50 seeds per plant according to the method of pollination the previous year.

TABLE 10.—*Frequency distribution of seed size in relation to method of pollination the previous year.*

Weight of 50 seeds, gram	Number of seeds	
	Open pollinated	Self-pollinated
0.1001–0.1300	4	8
0.1301–0.1400	5	6
0.1401–0.1500	19	11
0.1501–0.1600	24	16
0.1601–0.1700	16	4
0.1701–0.1900	11	11
0.1901–0.2900	13	7
Total	92	63

The weight of 50 seeds from different plants varied from 0.1000 gram to 0.2900 gram. When the frequencies are grouped into these seven classes in order to secure at least five plants in each class, the seed weight classes may be compared with the number of plants obtained from open-pollinated vs. self-pollinated seed by means of the X^2 test. From $X^2 = 9.048$, for six degrees of freedom, P lies between 0.2 and 0.1, and it may be concluded that method of pollination did not significantly affect seed weight.

CORRELATION STUDIES

In Table 11 are given the simple correlation coefficients when height of plants (x), yield of plants (y), and number of inflorescences per plant (z) are correlated in all combinations.

TABLE 11.—*Correlation coefficients between yield, height of plants, and number of inflorescences per plant.*

Year	No. of plants	Correlation coefficient of*			1% level of significant for r
		xy	xz	yz	
1934	54	+.5542	+.4876	+.8516	.3541
1935	158	+.4884	+.4351	+.6435	.2080

*x = height of plant, z = number of inflorescences per plant, y = yield of plant.

The 1934 data are from open-pollinated plants only. The 1935 data are from plants open pollinated in 1935 but arising from either inbred and non-inbred seed the previous year. It was noted previously that inbreeding had an appreciable effect on yield but had no significant effect on height of plants or number of inflorescences. It would seem legitimate, therefore, to combine all the 1935 data in calculating the correlation coefficients.

All correlation coefficients in Table 11 are positive and highly significant, exceeding the 1% level of significance. It is apparent, therefore, that height of plants and number of inflorescences were positively associated with yield and height of plants with number of inflorescences. The correlation between number of inflorescences and yield was particularly high in both years, being + .851~~8~~6 in 1934 and + .6435 in 1935.

In Table 12 is given the frequency distribution of yield of plants in relation to color of seed.

TABLE 12.—*Frequency distribution of yield per plant in relation to seed color of rape.*

Yield per plant, grams	Number of plants with		Total
	Red or purple seed	Yellow seed	
0.1– 5.0	5	4	9
5.1–15.0	15	16	31
15.1–25.0	12	29	41
25.1–35.0	17	14	31
35.1–45.0	8	8	16
45.1–85.0	6	24	30
Total	63	95	158

Applying a X^2 test for independence to the data of Table 12 gave $X^2 = 12.306$. For five degrees of freedom P would fall between 0.05 and 0.02, indicating that an association existed between seed color and yield among these plants, high yield being associated with yellow and low yield with red color.

In Table 13 is given the distribution of plant height in relation to color of seed.

TABLE 13.—*Frequency distribution of height of plants in relation to seed color in rape.*

Height of plant, cm	Number of plants with		Total
	Red or purple seed	Yellow seed	
40–60	7	11	18
61–70	15	17	32
71–80	22	25	47
81–90	12	26	38
91–130	7	16	23
Total	63	95	158

Grouping the data as indicated in Table 13, X^2 for independence was 3.550. For four degrees of freedom P lies between 0.5 and 0.3, indicating that plant height was not associated with color of seed.

In Table 14 is given the frequency of plants varying in number of inflorescences classified according to color of seed.

TABLE 14.—*Frequency distribution of the number of inflorescences per plant in relation to seed color.*

Number of inflorescences per plant	Number of plants with		Total
	Red or purple seed	Yellow seed	
6–15	8	8	16
16–20	14	7	21
21–25	6	17	23
26–30	8	19	27
31–35	13	18	31
36–40	6	11	17
41–70	8	15	23
Total	63	95	158

Applying a X^2 test for independence to the above data, $X^2 = 10.430$. For six degrees of freedom P falls between 0.2 and 0.1, indicating independence of number of inflorescences and color of seed.

In Table 15 are given the frequencies of weight per 50 seeds in relation to seed color.

TABLE 15.—*Frequency distribution of seed weight in relation to seed color.*

Weight of 50 seeds, gram	Number of plants with		Total
	Red or purple seed	Yellow seed	
0.1001–0.1300	7	5	12
0.1301–0.1400	5	6	11
0.1401–0.1500	17	13	30
0.1501–0.1600	17	23	40
0.1601–0.1700	7	13	20
0.1701–0.2900	9	33	42
Total	62	93	155

Grouping the frequencies as indicated in Table 15, X^2 for independence was 11.637. So high a value of X^2, for five degrees of freedom, would arrive between 5 and 2 times in 100 trials by random sampling alone from unassociated characters. It must be concluded, therefore, that seed color was associated with seed weight in the case of these plants. The yellow seeds were the larger.

DISCUSSION

In general, open pollination is more efficient than self pollination as a means of securing a large supply of seed from rape. An amount of seed adequate for breeding purposes can be secured by inbreeding under paper bags, however. Most of the plants inbred for the first time were moderately self fertile. Exceptions occurred, however. Lines No. 34–4 and 76–2 produced only 0.3 and 0.2 gram of seed, respectively. That this low seed setting was not due to a lack of vigor of the plants was evident by the fact that these plants attained nor-

mal vegetative growth, as shown by height and number of inflorescences per plant. Apparently rape plants vary genetically in ability to set seed when selfed.

While inbreeding, in general, resulted in a marked loss in vigor, some lines seemed to be very promising. Lines 12–1, 24–3, 34–1, 38–2, 54–2, 60–1, 60–2, 60–3, and 60–5 all yielded more than 45 grams of seed per plant. Only further inbreeding can demonstrate whether rape can be carried along by continuous inbreeding. The results from one generation inbreeding of selfing seem promising, however.

Mohammad (4) found that in a yellow-seeded, self-fertile form of sarson some promising inbred lines could be isolated from ordinary mixed varieties. In the writer's tests such would seem also to be the case, this conclusion being based on only two years' work, however.

SUMMARY

1. The paper bag method of selfing has been used to secure inbred seed of rape.
2. The average percentage of seed set was 21.46 in the self- and 63.03 in the open-pollinated inflorescences in the studies conducted in 1934. The average percentage of seed set in 1935 was 23.74 in the self- and 71.47 in the open-pollinated inflorescences.
3. Self pollination results in a decrease in yield of the subsequent progeny of rape. The yield of plants from inbred seed was about one-third less than in the open-pollinated progenies.
4. Self pollination for one year has no effect on the height and number of inflorescences per plant.
5. Significant positive correlation coefficients between yield, height of plants, and number of inflorescences per plant were found.
6. No relationship between seed color and height and number of inflorescences per plant was found, but an association existed between seed color and yield among these plants as indicated by the X^2 test, high yield being associated with yellow and low yield with red color.
7. A significant association was found between seed color and seed size, small seed being associated with red or purple and large seed with yellow seed color.
8. Inbreeding as a method of producing true breeding lines seems to be a promising mode of attack in rape improvement.

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THE DROUTH RESISTANCE OF QUACK GRASS UNDER VARIOUS DEGREES OF FERTILIZATION WITH NITROGEN[1]

S. T. Dexter[2]

In considering the hazards to which quack grass (*Agropyron repens*) may be subjected deliberately in any control program, it has seemed desirable to attempt to segregate various of the injurious factors. There is, for example, the possible factor of starvation for organic food for respiration, sugars, starches, etc. If a plant can be induced to use up these foods without due replenishment, it will die. Drouth and freezing injury are other plant hazards, the influence of which may be conditioned by previous physical environment and by various stages of organic nutrition induced by management.

Various theories have been advanced to explain differences in drouth resistance. Rosa[3] stresses the rôle of the pentosans, while Newton and Martin[4] emphasize the "bound water" differences. The process of hardening for drouth resistance has been compared with the process of hardening for cold resistance, and attention has been called to the similarities between them. In general, one might expect more ability to withstand drouth injury in plants that had been grown under conditions that would prevent rapid growth and that would favor accumulation of hemicelluloses and a high percentage of dry matter.

MATERIALS AND METHODS

Quack-grass rhizomes were obtained from two locations. Those obtained from Lake City, Mich., about 125 miles north of East Lansing, were from soil very low in organic matter; those obtained at East Lansing were from soil rather high in organic matter and which had previously grown alfalfa. Certain plats were fertilized with ammonium sulfate in the early spring at both places. Those at East Lansing had been fertilized the previous year as well.

Quack grass rhizomes were dug, washed, and dried of superficial moisture. Samples were weighed out for the various treatments. The work reported in this paper is a continuation of that recently reported[5] and may be divided into three parts, as follows: First, the recovery in the greenhouse of rhizomes sprouted in a seed germinator but never exposed to drouth; second, the recovery in the germinator and in the greenhouse of rhizomes exposed to drouth directly after being dug; and third, the recovery in the germinator of rhizomes exposed to drouth after periods of sprouting.

[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 291 (New Series). Received for publication March 12, 1937.

[2]Research Associate in Farm Crops.

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PART I

It has been noted previously that rhizomes from sod fertilized with ammonium sulfate sprouted more vigorously than rhizomes from unfertilized sod. A peculiarity frequently arising in this work was that many rhizomes that appeared to be in perfectly healthy condition failed to sprout. This was particularly notable in the case of plants grown in the minus nitrogen nutrient. To investigate this point further, samples were dug at Lake City on June 17 from plats that received 0, 500, and 2,000 pounds of ammonium sulfate per acre, respectively. Samples were prepared and placed between moist blotters in the seed germinator. Table 1 shows the results of this treatment.

TABLE 1.—*Number, length, and weight of new shoots produced in the seed germinator from rhizomes fertilized at the rates shown.*

Pounds of ammonium sulfate per acre	New shoots removed on July 10			New shoots removed on July 31		
	No.	Length, in.	Green weight, grams	No.	Length, in.	Green weight, grams
0	15	12.5	0.37	7	7	0.08
500	62	145	2.18	38	138	1.20
2,000..	53	139	2.05	17	50	0.22

Precisely the same type of data is shown here as was reported before, with the exception that in the case of the heavy fertilization rhizome formation becomes somewhat restricted and is not as persistent as in the case of the more moderate fertilization. As before, the failure of healthy rhizomes to sprout materially was particularly notable in the case of the rhizomes from unfertilized plats.

To see if they could be brought into more vigorous vegetation, the rhizomes were removed from the blotters on July 31 and placed in pots in the greenhouse where they were covered to a depth of about an inch with moist sand and were well fertilized. Fig. 1 shows the recovery in the various treatments. None of the shoots forming on the 2,000-pound set reached the surface. One bud on the rhizomes from the 500-pound set developed leaves that reached the surface, while the pot was filled with shoots from the rhizomes that received no fertilizer.

These findings correspond with the experience in small field plats in which unfertilized sod was more persistant under eradication practices. As previously stated[6], "Possibly these unfertilized plants were able to obtain nitrogen from the soil for later growth by which time the high nitrogen plants may have exhausted their carbohydrate supply by vigorous initial growth".

PART II

Samples of the rhizomes used above were also subjected to drouth in the form of exposure on the laboratory table for various periods of

[6]See footnote 5.

time ranging from 24 hours to 288 hours. These rhizomes were dug from extremely dry soil. The spring had been so free from rain that very little growth had occurred in the unfertilized plats. The actual yields, in pounds of dry matter per acre, were as follows: 417 pounds for the unfertilized plat, 1,266 pounds for the 500-pound treatment, and 2,265 pounds for the plats that received 2,000 pounds of ammonium sulfate per acre. It would seem that all these rhizomes might well have been hardened to drouth conditions in the field.

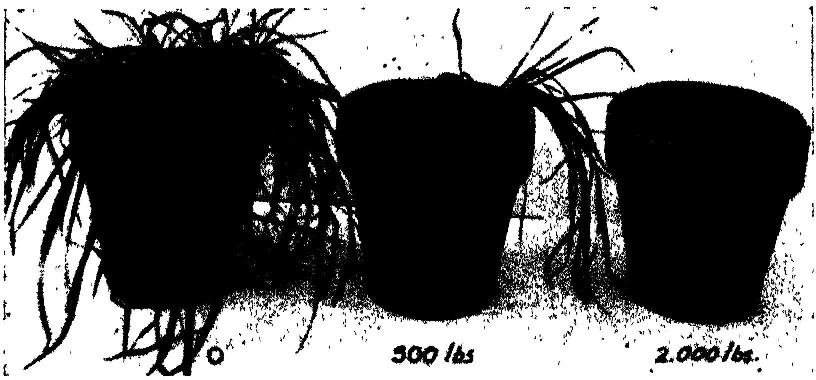

FIG. 1.—Recovery in sand of quack grass rhizomes from plats receiving 0, 500 and 2,000 pounds of ammonium sulfate per acre, respectively. The rhizomes were sprouted for 6 weeks in a seed germinator before transferring to sand.

After exposure to drouth, the samples were placed between moist blotters in a seed germinator. On samples that were exposed to more than 24 hours of drouth no sprouts appeared. On the samples exposed to 24 hours of drouth a total of but three sprouts appeared in the three samples, indicating that killing was practically complete in the least severe treatment.

The high-nitrogen rhizomes were a mass of mold within a day or two after being remoistened and placed in the germinator, while the low-nitrogen rhizomes remained bright and did not decay until much later, although they never did sprout. The greater the exposure to drouth, the more rapid and complete was the invasion by molds. Molding was more severe on the 2,000-pound set than on the 500-pound series. As in the previous work, it seemed peculiar that rhizomes that appeared to be uninjured, as did the low-nitrogen rhizomes, should fail to sprout. Possibly, under field conditions, such rhizomes, not being attacked by molds, might recover. Table 2 shows the weights of 10-gram samples after the various periods of drying.

On July 1, samples were dug at East Lansing, from the plats which had received no fertilizer and from those that had been heavily fertilized both in 1935 and 1936. These were exposed on wire trays for periods of 6, 12, 18, 24, and 48 hours, after which they were placed between moist blotters and put in the seed germinator. The new shoots were cut off at intervals, counted, and weighed in an attempt to ascertain the recovery from the various degrees of drouth injury. Mold-

TABLE 2.—*Effect of drying upon weight of 10-gram samples of rhizomes taken from plats receiving different fertilizer treatments.*

Period of drying, hours	No. of samples	Weight after drying, grams		
		No fertilizer	500 lbs. fertilizer	2,000 lbs. fertilizer
24	5	5.74	5.27	4.97
48	4	5.42	4.86	4.55
96	3	5.34	4.77	4.47
144	2	5.43	4.84	4.50
288	1	5.14	4.80	4.43

ing was particularly notable on injured rhizomes that had received heavy fertilization with nitrogen.

With each set of samples, representing no fertilizer and 500 and 1,000 pounds of ammonium sulfate, the increase in injury was very evident as the exposure to drouth was increased. The injury from 6 hours drouth was almost negligible and was evident only through the slight molding of the samples from the fertilized plats. The injury from 12 hours drouth was intermediate and that from 18 hours definitely more. In the case of the 24-hour exposures, injury was very severe in the high nitrogen samples, although a good many rhizomes were able to sprout. Most of the rhizomes were dead in all samples exposed for 48 hours, although the samples from unfertilized plats were injured least. Tables 3 and 4, are a condensation of the data taken.

TABLE 3.—*The number of sprouts removed from samples of quack grass rhizomes sprouted in a seed germinator after exposure to drouth on July 1.*

Date cut	Drouth 0 and 6 hours		Drouth 12 and 18 hours		Drouth 24 and 48 hours	
	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized
July 1	35	56	34	39	11	10
July 30	28	24	24	23	10	8
Aug. 20	26	19	15	11	6	3
Sept. 5	13	12	9	6	5	2
Sept. 24	12	7	6	4	2	1

TABLE 4.—*The green weights in grams of sprouts removed from samples of quack grass rhizomes sprouted in a seed germinator after exposure to drouth on July 1.*

Date cut	Drouth 0 and 6 hours		Drouth 12 and 18 hours		Drouth 24 and 48 hours	
	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized
July 11	1.17	1.52	0.89	1.19	0.18	0.31
July 30	0.47	0.31	0.54	0.36	0.28	0.22
Aug. 20	0.89	0.35	0.51	0.24	0.17	0.09
Sept. 5	0.20	0.19	0.19	0.13	0.08	0.04
Sept. 24	0.25	0.11	0.12	0.04	0.04	0.01

The number of sprouts removed on each date from the 0- and 6-hour exposures are averaged as are those from the 12- and 18-hour and the 24- and 48-hour exposures, and in each case the results are represented by one figure. The values from the 500-pound treatment and the 1,000-pound treatment are also averaged and included as one figure. The 1,000-pound treatment samples were almost always more severely injured than the 500-pound samples. A similar condensation is offered for the weights taken.

The two tables bring out about the same facts. Under all except the most severe drouth conditions, the high-nitrogen samples sprouted more vigorously for the first 10 days than did the low-nitrogen samples. After that, the low-nitrogen samples were always stronger. The data do not bring out fully the relative condition of the high- and low-nitrogen samples under the more drastic treatments. The rhizomes from unfertilized plats remained relatively bright and free from decay, while the samples from fertilized plats became a mass of mold within a few days after they were placed in the germinator. In the 24- and 48-hour drouth samples, the newer, younger rhizomes appeared to survive drouth far better than the mature rhizomes. This tendency can be observed by computing the average weight per sprout in the more drastic treatments where it is found that the sprouts are larger than in the check. In other words, the relatively weak rhizomes died and those that remained sent out large sprouts.

In order to bring out the relatively stronger condition of the low-nitrogen samples, on September 24 the rhizomes were set in sand in the greenhouse. The 0 and 6-hour samples were combined and the 12-, 18-, 24-, and 48-hour samples also, but the 500- and 1,000-pound treatments were kept separate.

Fig. 2 shows the relative recovery of the various samples. There is rather strong recovery in all the samples from the mild drouth treatment. The recovery from the drastic treatment is still good in the case of the samples from unfertilized plats, but is poor as the fertilizer treatments increased.

In the germinator, the sprouts of the high-nitrogen rhizomes developed quickly, leaves formed, and decay of the new shoots set in within a few days. On the contrary, the sprouts on the low-nitrogen rhizomes developed slowly, the leaves formed at a much later date, and decay of the new shoots seemed almost indefinitely postponed. These new shoots, as has been shown previously, were higher in moisture and in nitrogen content when from fertilized than when from unfertilized rhizomes. The browning and disintegration of the leaves on the new shoots seemed independent of molding, which merely followed their death.

In plats plowed at Lake City about June 25, the early vigorous sprouting followed by decay and death of the rhizomes was clearly evident in the fertilized plats. When unfertilized plats were examined in the late fall, the sod was still firm and the rhizomes still bright and covered with hard, sharp sprouts.

It is interesting to note the difference in drouth resistance in the samples dug at Lake City on June 17 and those dug at East Lansing

on July 1. According to previous experiments,[7] those dug at East Lansing had passed the stage of easiest eradication, while those at Lake City were perhaps at about their most sensitive stage. This point is receiving further consideration.

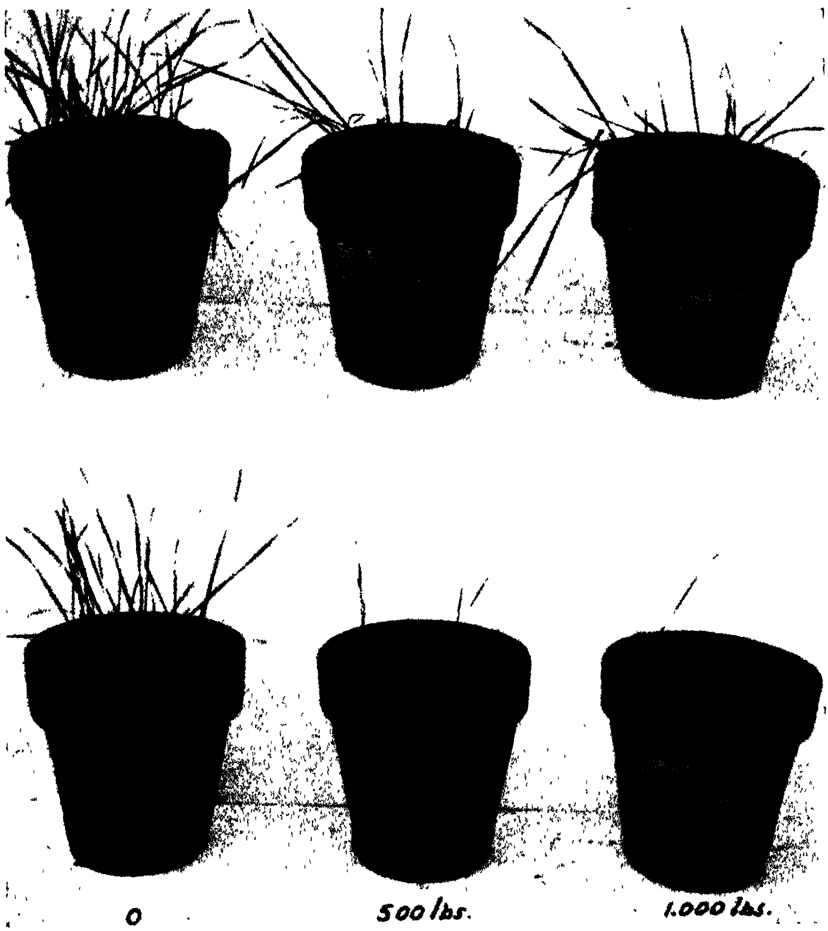

FIG. 2.—Recovery in sand of quack grass rhizomes from plats receiving 0, 500, and 1,000 pounds of ammonium sulfate per acre, respectively. The rhizomes in the upper pots were exposed to 0 to 6 hours drouth with little injury; in the lower pots, the drouth treatment was 12 to 48 hours. The rhizomes were sprouted for about 7 weeks before transferring to sand.

An experiment was run with rhizomes dug at East Lansing on July 10 to determine the effects of alternate drying and moistening. The rhizomes were exposed in the laboratory for 15 hours, then placed in the germinator with virtually 100% humidity for 9 hours, repeating this treatment for a number of days. Again it was evident that the younger rhizomes were more drouth resistant. Six dryings in this way

[7]See footnote 5.

killed the old rhizomes, while the younger rhizomes survived 10 exposures to drouth. Mold was again very evident in the high-nitrogen samples that received more than two dryings. In all cases the rhizomes absorbed water during the moist period, but during the next exposure to air in the open laboratory lost more than they had gained.

PART III

About the middle of October, rhizomes were dug at East Lansing from plats that had been unfertilized and from others that had received heavy fertilization with ammonium sulfate in both 1935 and 1936. After two full growing seasons under these treatments, rather striking differences had shown up in the plats. Most of the old rhizomes of the fertilized sod were brown and dying or dead and the sod was characterized by a thick mass of short fibrous roots, although with numerous new rhizomes. The unfertilized sod was a mass of old rhizomes still bright in color. The fertilized sod formed new rhizomes at an earlier date in the fall than did the unfertilized sod, although there was not much difference in quantity of new rhizomes by the time the ground froze. At that time the new and the old rhizomes were almost indistinguishable in the unfertilized sod, while they were greatly different in the fertilized sod since the old rhizomes were either dead or dying.

Due to the condition of the rhizomes in the fertilized plats, it was somewhat difficult to secure samples that were free from incipient decay and browning. No such difficulty was experienced with the rhizomes from unfertilized sod. In this experiment, the rhizomes were sprouted in the germinator for 0, 5, 10, and 20 days respectively, following which samples from each sprouting treatment were exposed to drouth for 0, 8, 18, and 48 hours. After exposure to drouth, the samples were returned to the moist blotters in the germinator for recovery. As in all previous experiments, the rhizomes from fertilized plats sprouted very vigorously at first, while the others sprouted rather meagerly. The effect of sprouting on drouth resistance was far more evident in the case of the high-nitrogen samples than in the case of the low-nitrogen samples. Molds were very prominent on the samples from fertilized plats. In all previous samples, the low-nitrogen rhizomes have appeared to form roots more strongly and shoots less strongly than the high-nitrogen samples. This tendency seemed aggravated by the exposure to drouth. After being returned to the blotter pads following sprouting and drouth, the low-nitrogen rhizomes formed many new roots which penetrated into and through the blotter, while the high-nitrogen rhizomes formed virtually no new roots. Fig. 3 shows this characteristic. Even though the low-nitrogen rhizomes sprouted poorly in many cases when returned to the blotters, they still retained their bright color and it was difficult to decide whether they were dead or not. Many of the high-nitrogen rhizomes were so weak when brought in from the field that they soon died on the pads after forming new shoots which, as previously stated, tended to darken and disintegrate shortly after vegetative leaves formed. This occurred without exposure to drouth as well as after drouth injury. Table 5 gives a numerical estimate of the condition of the samples of rhizomes after time had been given for recovery in the germi-

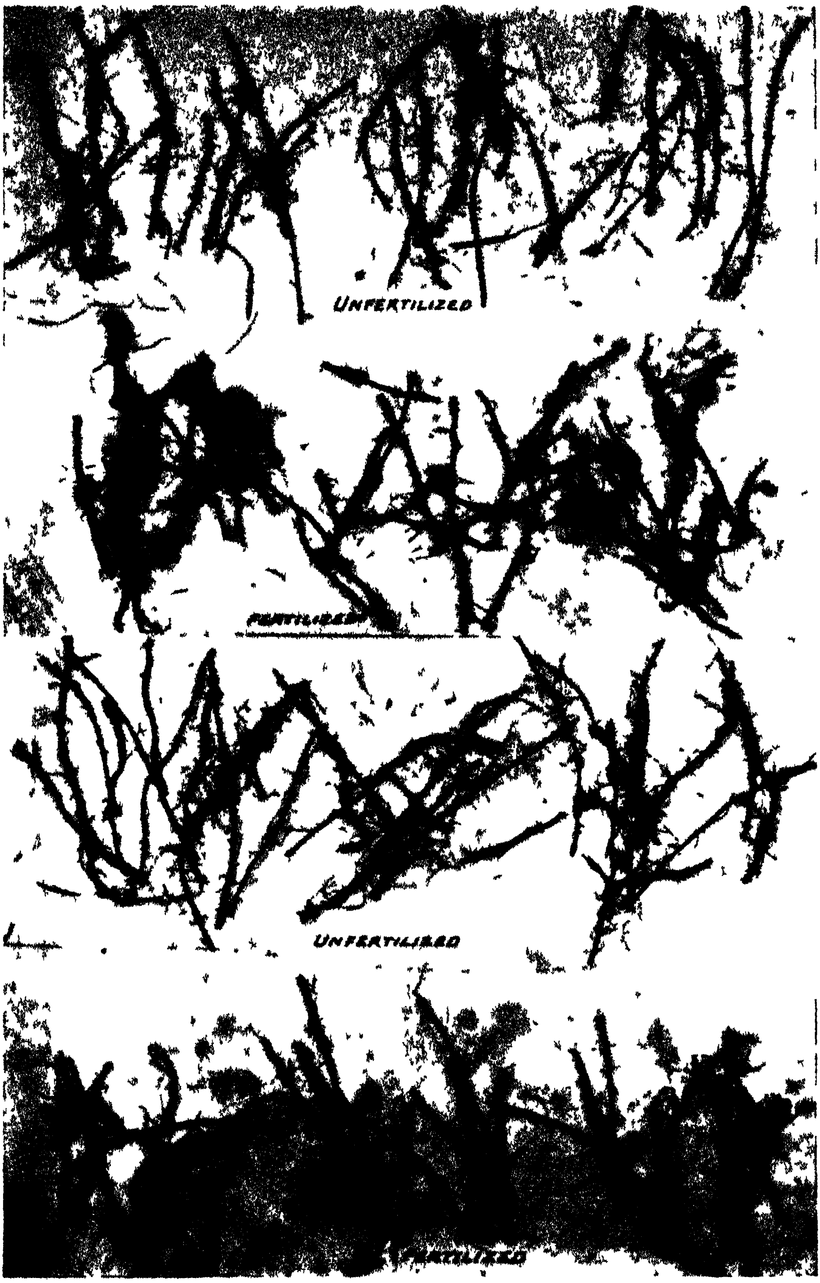

FIG. 3.—The two upper samples of rhizomes were sprouted for 10 days before exposing to 18 hours of drouth. The two lower samples were sprouted for 20 days before exposing to 18 hours of drouth. The photographs show the recovery in the germinator after such exposure. Note the mold on the samples from fertilized plats and the fibrous roots on the unfertilized rhizomes.

nator, following the initial sprouting and exposure to drouth. In the table the value 10 was taken to indicate a strong, bright-colored rhizome sprouting and not decaying. Zero indicates no sprouting, the rhizomes apparently dead.

TABLE 5.—*Condition of rhizomes after recovery from sprouting and subsequent drouth as judged by growth of roots and shoots, color, and molding.*

Treatment	Sprouted, none				Sprouted, 5 days			
	0	8 hrs.	18 hrs.	48 hrs.	0	18 hrs.	18 hrs.	48 hrs.
Unfertilized ...	10	8	5.5	1.5	9.5	6.5	2.5	0.5
Fertilized...	8	8.5	4	0.5	5	4.5	1	0
	Sprouted, 10 days				Sprouted, 20 days			
	0	8 hrs.	18 hrs.	48 hrs.	0	8 hrs.	18 hrs.	48 hrs.
Unfertilized....	9.5	2	3	0	7	6.5	4	0
Fertilized	4.5	0.8	0	0	2.5	2.5	0	0

The rhizomes from unfertilized plats showed some injury from sprouting before exposure to drouth, but not nearly the injury that was indicated in the fertilized samples. This might be expected in view of the relatively scanty sprouting of the low-nitrogen samples. Fig. 3 shows the relative conditions of high- and low-nitrogen samples after exposure to 18 hours of drouth, following 10 and 20 days of sprouting, respectively. The low-nitrogen rhizomes formed new roots and shoots fairly abundantly and were bright in color, while the high-nitrogen rhizomes had neither shoots nor roots and were covered with mold. Precisely these same things could be observed in the field plats this past summer. The rhizomes in fertilized plats sprouted quickly, were possibly injured somewhat by drouth, and molding began to disintegrate the sod. The rhizomes in unfertilized plats sprouted very slightly and no mold was seen.

Rather extensive field trials have been made and others are in progress which are planned to test the applicability of these principles to the control of quack grass on a field scale.

SUMMARY

1. Rhizomes of quack grass from plants grown in field plats fertilized with ammonium sulfate were found to sprout more vigorously and to be less able to recover in soil after sprouting than rhizomes similarly treated but from unfertilized soil.

2. No marked difference was seen in the drouth resistance of rhizomes from fertilized and unfertilized plats at the time they were brought in from the field.

3. Rhizomes from the fertilized plants were more subject to invasion by molds than were rhizomes from unfertilized plants, particularly if somewhat injured by drying in the air.

4. A period of sprouting before exposure to drouth was more injurious to rhizomes from fertilized soil than to rhizomes from unfertilized soil.

EXPERIMENTS ON THE PLANTING DISTANCE IN VARIETAL TRIALS WITH MILLET, *SETARIA ITALICA* (L) BEAUV.[1]

H. W. Li and C. J. Meng[2]

In the varietal trials for millet breeding work, the hill system has been used, namely, spacing the plants in the rows as commonly practiced by farmers. It was found from previous experiments[3] that, "the closer the plants were set, the higher was the yield, but less stooling per plant. By the use of analysis of variance, no significance was found in the yield of the different planting distances, i. e., 2, 4, 6, 8, and 10 inches apart, but there was a significant difference for the number of stools per plant for the different planting distances. The regression of yield on stooling was not significant".

Since there was only one variety under observation, there was probably no justification in making the above conclusion based on one year's data only; therefore, the same experiment was repeated with some modification and the results are reported in this paper.

MATERIALS AND METHODS

The variety used in the previous experiment was selected strain No. 48, which is a high yielder, stools well, and matures fairly late. In many localities of Honan Province and elsewhere in North China, many varieties are grown that do not have many tillers or that have none whatsoever. In order to meet this condition, selection No. 1588, a practically non-tillering variety, was also used. In this way, it was possible to see the comparative reactionary differences for the treatments when grown under almost identical conditions. These two strains of millet were arranged to be grown in a 10 by 10 Latin square as in the following scheme:

A2	B2	A4	B4	A6	B6	A8	B8	A10	B10
B2	A2	B4	A4	B6	A6	B8	A8	B10	A10
A4	B4	A6	B6	A8	B8	A10	B10	A2	B2
B4	A4	B6	A6	B8	A8	B10	A10	B2	A2
A6	B6	A8	B8	A10	B10	A2	B2	A4	B4
B6	A6	B8	A8	B10	A10	B2	A2	B4	A4
A8	B8	A10	B10	A2	B2	A4	B4	A6	B6
B8	A8	B10	A10	B2	A2	B4	A4	B6	A6
A10	B10	A2	B2	A4	B4	A6	B6	A8	B8
B10	A10	B2	A2	B4	A4	B6	A6	B8	A8

A = Strain No. 48.
B = Strain No. 1588.
2, 4, 6, 8, 10 are the distances in inches between plants in the row.

[1]Contribution from the College of Agriculture, Honan University. Received for publication March 22, 1937.

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[3]Li, H. W., Meng, C. J., and Liu, T. N. Field results in a millet breeding experiment. Jour. Amer. Soc. Agron., 28:1–15. 1936.

This can be combined into a 5 by 5 Latin square if the results of the plats diagonally to one another in the same block are added together, as the two A2's, or the two B2's, etc. In this way, A and B can be separated in the calculation in case of necessity. Each plat has three rows, and each row is 15 feet in length with 1 foot between rows. The experimental land is very level, sandy loam in character, and has been used exclusively for breeding experiments for the past few years. However, this is an entirely different piece of land from that used in the previous experiment.

Sowing was done on May 28, 1935, a month earlier than in the previous experiment, but harvesting was carried out practically on the same date in both years. The number of functional tillers per plant, the height of plant in inches, and the length of the longest earhead in each plant in 1/10 of an inch, were recorded in the field (average of 16 plants of the central row of each plat).

Earliness was recorded for each plat according to the time when heading was taking place. The figures were obtained by regarding the plat that headed out first as zero with each plat that headed out subsequently being given a number corresponding to the number of days that intervened. The yield in grams was determined after harvest, using the average of three rows in the plat. The weight in grams of 10,000 shelled kernels was also obtained (average of 10 samples in each plat taken at random).

EXPERIMENTAL RESULTS

The results for strain No. 48 in both years were quite comparable with respect to yield and the number of functional tillers per plant, as shown in Table 1

TABLE 1.—*Yield and tillers per plant for strain No. 48.*

Distance between plants in rows, in.	Yield, grams*		Tillers per plant	
	1934	1935	1934	1935
2	269.8	820.11	2.894	3.64
4	262.8	840.99	3.624	4.19
6	252.4	776.11	3.750	5.08
8	238.2	769.93	3.783	6.49
10	237.6	719.13	4.454	6.85

*Average of three rows.

Results for both years agree quite closely with one another in a general way. By taking advantage of more fertile land and favorable climatic conditions when the crop was grown in 1935, both yield and tillers per plant were much higher than in 1934. In general, it may be safely said from the results of these two years, that the closer the plants are set the higher is the yield but the smaller is the number of tillers per plant for this variety. Records for the other characters mentioned above were not taken in 1934, so no comparable results can be given here.

The comparative results of the two selected strains in regard to the different characters under study for their respective planting distances are given in Table 2.

TABLE 2.—*Comparison of the two selected strains in the different characters under study for their respective planting distances.*

Characters	Strain	Planting distances in inches					Standard error
		2	4	6	8	10	
Yield	No. 48	820.11*	840.99	776.11	769.93	719.13	23.16
	No. 1588	705.68	543.86	463.90	430.41	369 29	
	Difference	114.43	297.13	312.21	339.52	349.84	
Tillers	No. 48	3.64	4.19	5.08	6.49	6.85	0.17
	No. 1588	1.14	1.14	1.30	1.18	1.34	
	Difference	2.50	3.05	3.78	5.31	5.51	
Height	No. 48	41.59	41.73	42.41	42.00	41.89	0.404
	No. 1588	37.64	37.23	37 62	37.10	37.59	
	Difference	2.95	4.50	4.79	4.90	4.30	
Earliness	No. 48	9.9	10.7	11 6	11.8	12 2	0.26
	No. 1588	1 8	2 5	3 1	3 3	3.4	
	Difference	8 1	8.2	8 5	8 5	8.6	
Length of earhead	No 48	44.15	51 14	54 66	52.84	55 41	1.08
	No. 1588	58.97	67.55	70 40	73.11	74.81	
	Difference	14.82	16.41	15 74	20.27	19.40	
Weight of kernels	No. 48	23.13	23.48	23.58	23.49	23.78	0.1404
	No 1588	26 91	27.48	27.73	27 55	28.20	
	Difference	3.78	4 00	4 15	4.06	4 42	

*Figures given are averages of 10 plats.

It can be seen from Table 2 that the two strains of millet differ significantly from each other in all the characters under study judging from the standard errors given for their respective characters. Strain No. 48 is a better yielder, taller in stature, and has more functional tillers per plant; but on the other hand, strain No 1588 matures earlier and has a longer earhead and heavier kernels than strain No. 48. These results hold true for all the planting distances concerned.

If the various values in Table 2 are represented in percentage of their respective mean for each character under study in graphic form, as shown in Fig. 1, information is obtained which is not clearly seen otherwise even though in so doing we do cause some exaggeration. The yield curve of strain No. 48 goes downward as the distance between plants increases. On the other hand, however, curves for tillering, earliness, and length of earhead go upward as the plants are set farther apart in the row. The curves for height of the plant and weight of the kernels remain unchanged with the change in distance between plants, although there is some tendency for them to go upward. The curve for tillering is the steepest of all and this is a very important point as will be described in more detail later.

The yield curve of strain No. 1588 drops abruptly as the distance between plants increases. Earliness and the length of the earhead vary directly with the increase in distance between the plants. Tillering shows some variation for the different planting distances and certainly behaves very differently from that of strain No. 48. The num-

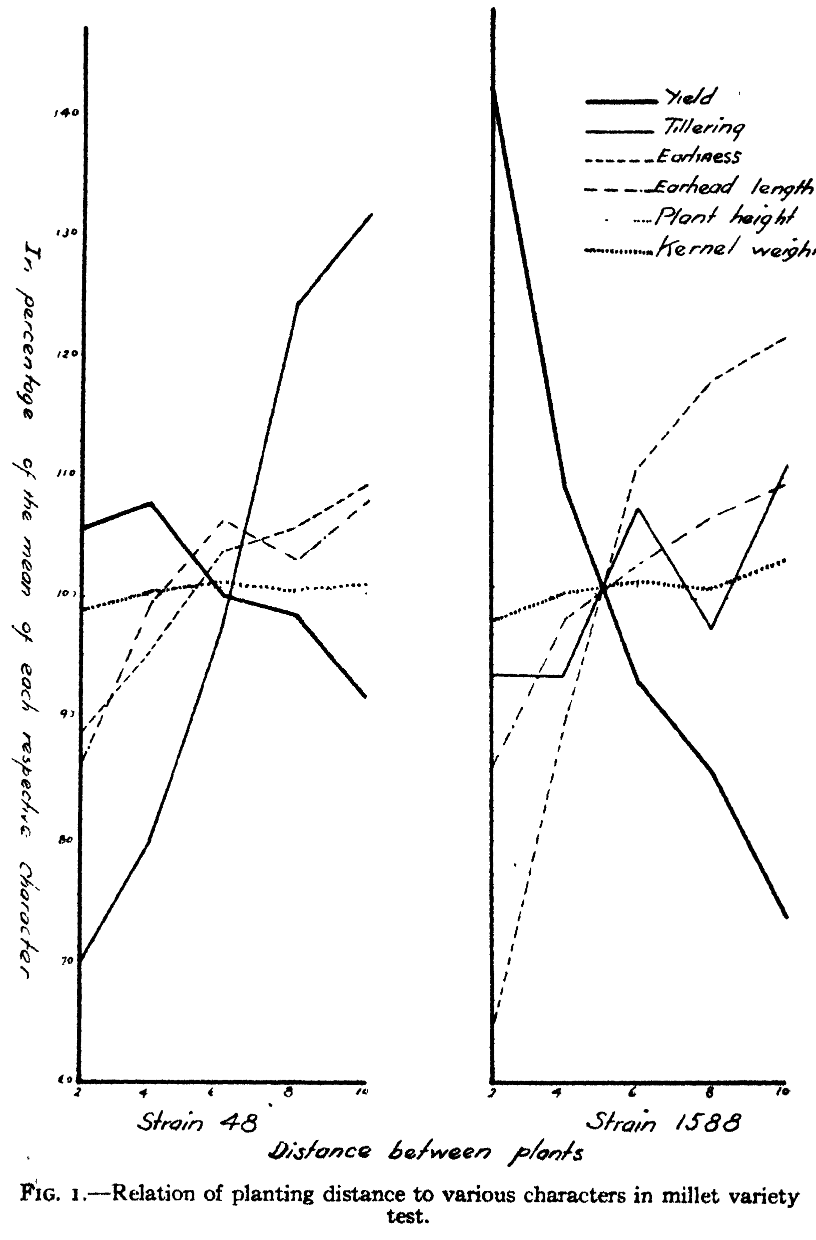

FIG. 1.—Relation of planting distance to various characters in millet variety test.

ber of tillers per plant increases very little in spite of the increase in the distance between plants in the row. This explains why the yield of strain No. 1588 decreases so abruptly as the distance between plants in the row increases. The curves for height of plant and weight of kernels show a slight tendency to go upward as in strain No. 48.

Whether the differences for the average values of the different planting distances in all the characters under study are statistically significant is the important point. These differences are shown in Table 3.

From Table 3 it can be seen that the behavior of the two strains does not show much similarity. The yields for the various distances of strain No. 48 do not differ significantly from one another in the majority of cases. This was also true in the experiment of 1934. Strain No. 1588, however, behaves differently, almost all the differences in the yields for the various planting distances being significantly different from one another. This would mean, of course, that as the planting distance between plants in the row increases, the smaller is the number of plants per row, thus a decrease in yield. The same behavior occurs again in respect to weight of kernels. The differences are insignificant for strain No. 48 but significant for strain No. 1588.

The two strains behave in the same way for earliness, length of earhead, and height of the plant. Most of the differences in the former two characters are significant in both strains, but none of them is significant for height of plant. Significant differences are found, however, in number of tillers per plant for the various planting distances for strain No 48 but not in strain No. 1588. The ability to produce more tillers per plant when the distance between plants is farther apart in the row can certainly make up the loss in the number of plants of that row. This is to say that, as the distance between plants in the row is increased correspondingly fewer plants occur in the row but the number of functional tillers increases. Should we take an individual plant in the row as the unit instead of the row, the yield will vary directly as the increase in the distance between plants. Thus, the yield of the row is duly compensated in this way. Failure of strain No. 1588 to send out tillers would be disastrous in this respect. Although the increase in weight of kernels when the distance between plants is increased does help some in increasing yield, it is hardly enough to compensate for the loss in number of earheads per row.

SUMMARY AND CONCLUSIONS

In varietal trials with millet, the closer the plants are set in the row, the higher will be the yield in that row no matter whether one is dealing with a free-tillering variety or non-tillering varieties. With a free-tillering variety, the loss in number of plants per row will be compensated by the increase in number of tillers when the distance between plants in the row is increased. With a non-tillering variety, this loss will be manifested by a decrease in yield with an increase in the planting distance. There will be some compensation offered in this case by the increase in weight of kernels and length of earhead, but this is far from being sufficient.

TABLE 3.—*Differences between various planting distances in all the characters under study for both strains.*

Characters studied	Planting distance, in.	Strain No. 48				Strain No. 1588				S. E.
		4	6	8	10	4	6	8	10	
Yield	2	-20.88	44.00	50.18	100.98*	161.82*	241.78*	275.27*	336.39*	23.16
	4	—	64.88	71.06*	121.86*	—	79.90*	113.45*	174.57*	
	6	—	—	6 18	56.98	—	—	33.46	94.61*	
	8	—	—	—	50.80	—	—	—	61.12	
Tillering	2	-0.55*	-1.44*	-2.85*	-3.21*	0	-0 16	-0.04	-0.20	0.17
	4	—	-0.89*	-2.30*	-2 66*	—	-0.16	-0.04	-0.20	
	6	—	—	-1.41*	-1.77*	—	—	0.12	-0.04	
	8	—	—	—	-0 36	—	—	—	-0.16	
Height	2	-0.14	-0.82	-0.41	-0.30	0.41	0.02	0.54	0.05	.404
	4	—	-0.68	-0.27	-0.16	—	-0.39	0.13	0.36	
	6	—	—	0.41	0 52	—	—	0.52	-0.03	
	8	—	—	—	0.11	—	—	—	-0.49	
Earliness	2	-0.8*	-1.7*	-1.9*	-2.3*	-0.7	-1.3*	-1.5*	-1.6*	.26
	4	—	-0.9*	-1 1*	-1.5*	—	-0.6	-0.8*	-0.9*	
	6	—	—	-0.2	-0.6	—	—	-0.2	-0.3	
	8	—	—	—	-0.4	—	—	—	-0.1	
Length of earhead	2	-6.99*	-10.51*	-8.69*	-11.26*	-8.58*	-11.43*	-14.14*	-15.84*	1.08
	4	—	-3.52*	-1.70	-4.27*	—	-2.58	-5.56*	-7.26*	
	6	—	—	1.82	-0.75	—	—	-2.71	-4.41*	
	8	—	—	—	-2.57	—	—	—	-1.70	
Weight of kernel	2	-0.35	-0.45*	-0.36	-0.65*	-0.57*	-0.82*	-0.64*	-1.29*	.1404
	4	—	-0.10	-0.01	-0.30	—	-0.25	-0.07	-0.72*	
	6	—	—	0 09	-0.20	—	—	0.18	-0.47*	
	8	—	—	—	-0 29	—	—	—	-0.65*	

*Significant differences.

Ability to send out tillers is an inherent hereditary phenomenon of a variety. With more room given for expansion, thus providing more fertility, more moisture, and more sunlight, a free-tillering variety will take advantage of the situation to send out more tillers, while a non-tillering variety, on the other hand, will not be able to do so in spite of the opportunity presented.

In case of missing hills, moreover, a non-tillering variety will not be able to cope with the situation. Naturally, experimental errors of great magnitude will enter in. Thus, in varietal trials with millet, plants set closer together in the row, say 2 inches apart, will undoubtedly give the best results.

THE SPACING OF CORN IN THE WEST CENTRAL GREAT PLAINS[1]

JOSEPH F. BRANDON[2]

A RATE and spacing corn experiment was started at the Akron, Colo., field station in 1924 in keeping with a policy of finding all possible facts about the reaction of the different adapted crops to the environment of this general region. One purpose of the experiment was to gain information on the response of corn to different spacings of the plants in regularly spaced 44-inch rows and to a widening of the row space to 88 inches. A second purpose was to determine to what extent winter wheat yields were influenced by the spacing of a preceding corn crop.

The soil on which this experiment was conducted is fairly uniform. It is a light brown loam, characterized in the native state by a short-grass cover of buffalo and grama grasses. The surface soil is underlaid at a depth of 12 to 15 inches by a carbonaceous layer. The subsoil is slightly finer in texture than the surface and is interspersed by pockets of almost pure fine sand. This and other "hard land" soils are not nearly so well adapted to the growth of corn as the "soft", or more sandy soils, of the same general region.

MATERIALS AND METHODS

The spacing studies with corn were made in a 2-year rotation of corn and winter wheat. Three replications of each crop were grown each year. The winter wheat was grown on the land previously occupied by the spaced corn. The wheat was seeded at the rate of 3 pecks per acre in good season. During the earlier years of the experiment the seeding was done with an 8-inch disk drill. From 1927 on, a 12-inch furrow drill was used. Turkey, C. I. No. 1571, was the variety used.

The winter wheat stubble land was cultivated with a duckfoot or field cultivator soon after the wheat was harvested, with the front shovels removed, whenever weed infestation was bad enough to warrant. One or two early fall cultivations were sufficient to remove from 90 to 95% of the fall weed growth usual on stubble land in this region, and it did so without burying the trash and stubble of the preceding wheat crop. Occasionally it was deemed expedient to early spring cultivate with the same implement to correct a too badly weathered condition of the surface. In the spring, usually early in April, the land was plowed to a depth of 7 inches, and was then clean cultivated until the planting date of the corn. Usually one springtooth harrowing just in advance of seeding was all that was necessary.

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[2]Associate Agronomist. The writer is deeply indebted to Alvin Kezer and D. W. Robertson of the Colorado Agricultural Experiment Station for fine support and encouragement, and to the latter for helpful suggestions in the preparation of this paper; and to J. J. Curtis of the Division of Cereal Crops and Diseases of the U. S. Dept. of Agriculture for aid with this experiment since 1930. Mr. John S. Cole of the Division of Dry Land Agriculture, U. S. Dept. of Agriculture, designed this experiment in 1924.

The corn was planted with a corn planter equipped with furrow openers. Cultural experiments at this station show that there is no appreciable difference between yields from listed and surface planted corn in similar crop sequences. The corn was thinned to the specified spacings when it had reached a height of 4 to 8 inches, and was clean cultivated with cultivators and hoes during its growth period. It was harvested with a corn binder, shocked on the roadway to make way for seeding wheat, and husked when the fodder was field dry, usually in mid-October. The ear corn was weighed, and the weight was converted into bushels per acre on the basis of the apparent moisture present. No difference in moisture content of corn from different spacings was noticeable in any year. The type of season apparently was much more potent than the difference in spacing in determining the moisture content. It is felt that this method resulted in comparable acre yields between different spacings in every year.

The variety used was Akron Yellow, a smooth dent corn grown continuously at this station since 1917. It is one of the better varieties in the varietal experiment conducted at the station.

The corn was seeded in 44-inch, and in double spaced, or 88-inch rows Five of the 44-inch rows were considered to constitute a plat of 0.05 acre. Five of the 88-inch rows were considered to constitute a plat of 0.10 acre. The plats of each replication were seeded side by side in a single block. All outside plats were suitably bordered by additional rows with the same spacings as the nearest plats. A single row was used between the 44- and the 88-inch row plats

Faulty initial stands due to cutworms, to cold, wet periods immediately following seeding, or to tight crusting of the surface by dashing rains after germination but before emergence, sometimes prevented thinning the corn to the specified spacings. The shortage naturally was most frequent on the plats with close spacings Poor initial stands were obtained in 1926, 1927, 1929, 1930, and 1935. Stands on the first replication in 1929 were so poor that the yields were not used in the averages. The plan followed in years of poor stands was to thin the corn to leave the greatest possible number of evenly spaced plants. The desired spacings were 12, 18, 24, 30, and 36 inches in the 44-inch row plats, and 12 inches in the 88-inch row plat. The average spacings realized at the end of the 12-year period were 13.6, 18.9, 24.2, 30, 36, and 14.7 inches, respectively.

The data on spacing are shown in Table 1, together with the planned plant populations and the averages obtained.

CORN GRAIN YIELDS

Table 2 shows the average yearly production of ear corn in bushels per acre. The 1925 and 1934 plantings produced no grain on any of the spacings. The highest average yield for the 12-year period was 13.3 bushels per acre from plants spaced 24 inches apart in 44-inch rows. The yields from both closer and wider spacings ranged lower.

The double-spaced or 88-inch row method failed miserably as a means of insuring grain yields during the years of low or poorly distributed rainfall. This spacing did not produce the highest grain yield in a single one of the 10 years when grain was produced. The average yield, 9.2 bushels per acre, was less than that from any of the 44-inch row plats and only 69% as high as the yield from the most productive spacing. The average yield was only 70% of that from the 30-inch spaced plants in 44-inch rows, where the actual plant population realized per unit area was practically identical. (See Table 1.)

TABLE 1.—*Spacing of corn plants and average number of plants per acre obtained compared with the planned in the rate and spacing corn experiment at Akron, Colo., for the 12-year period 1924–1935, inclusive.*

Planned spacing of plants in the row, inches	Actual spacing, inches													Number of plants per plat	
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	Average	Planned	Actual
							44-inch Rows								
12	12	12	14.2	12	12	15.7	23.3	12	12	12	12	14	13.6	660	582
18	18	18	18	19.7	18	20.1	24.2	18	18	18	18	18.7	18.9	440	419
24	24	24	24	24	24	24	24.6	24	24	24	24	25.7	24.2	330	327
30	30	30	30	30	30	30	31	30	30	30	30	30	30	264	264
36	36	36	36	36	36	36	36	36	36	36	36	36	36	220	220
							88-inch Rows								
12	12	12	17.6	16.5	12	16	25.7	12	12	12	12	16.9	14.7	660*	539*

*The plants per plat for this spacing must be divided by 2 to be comparable with other spacings, as the plat was double the size of other plats.

TABLE 2.—*Grain yield of corn from five spacings in 44-inch rows and one spacing in 88-inch rows at the Akron, Colo., field station for the 12-year period of 1924–1935, inclusive.**

Planned spacing, inches	Yield per acre, bushels												Average yields, bushels		
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	All years	3 good years, 1927, 1929, and 1930	Other 9 years
							44-inch Rows								
12	2.7	0	11.5	41.1	2.4	32.9	41.2	1.1	7.7	2.5	0	7.4	12.5	38.4	3.9
18	2.7	0	11.6	33.4	4.7	30.3	42.1	1.6	11.2	4.1	0	8.8	12.5	35.3	5.0
24	4.5	0	12.7	30.9	9.5	27.0	42.1	1.6	13.8	7.8	0	9.4	13.3	33.3	6.6
30	7.4	0	14.1	28.2	10.8	25.2	35.1	1.7	12.6	9.3	0	12.2	13.1	29.5	7.6
36	9.5	0	13.0	21.1	10.9	21.3	32.6	1.8	13.4	10.1	0	14.2	12.3	25.0	8.1
Average	5.4	0	12.6	30.9	7.7	27.3	38.6	1.6	11.7	6.8	0	10.4	12.8	32.3	6.2
							88-inch Rows								
12	8.1	0	8.9	13.8	9.6	16.8	18.9	1.3	9.5	9.6	0	13.4	9.2	16.5	6.7

*Yields are the average of three replications, except in 1929 when the second and third replications only are used.

When the three good corn producing years of 1927, 1929, and 1930 were averaged, the highest yield secured was 38.4 bushels per acre from the 12-inch spaced plants in the 44-inch rows. Yields from the other spacings in regular width rows were progressively lower as the plant population per unit area was decreased. It is noteworthy that in 1930, when faulty initial stands forced a plant spacing essentially the same over the three more closely spaced plats, the yields from these plats were approximately equal.

In the average of the three good producing years, the yield from double-spaced rows was only 43% of that from the highest producing spacing in regular width rows and only 56% of that from an approximately equal plant population on the 30-inch spaced plants in 44-inch rows.

When the other 9 years were averaged, the highest yield was 8.1 bushels per acre from 36-inch spaced plants in 44-inch rows. Yields from the other spacings in regular 44-inch rows decreased as the plant population per unit area was increased.

In the 9 years of poor corn production the corn in 88-inch rows produced a yield practically equal to that in the 24-inch spacing in regular rows. The yield was nearly 1 bushel per acre lower than that from an approximately equal number of plants per unit area in the 30-inch spacing. The most productive spacing in poor years was 36 inches between plants in the row. In the average of all 12 years the most productive spacing was 24 inches in the row.

It is quite obvious that any recommendation to be made on planting rates depends upon whether the number of good and poor years included in this study are representative of the number to be expected over a long series of years. Results from crop rotation experiments conducted during the period 1908–36 indicate that they are.

The quality of the corn was good from all spacings during the 3 high-producing years. Careful measurement might have revealed slightly longer ears from the more thinly populated plats. During the other 9 years, similar quality ear corn was produced on the 24-, 30-, and 36-inch spaced plants in 44-inch spaced rows only. The other spacings produced nubbins which were hard to husk and shell. In 1931 nothing more than nubbins was produced on any spacing. The double spacing of rows did not improve the quality of the ear corn during the years of low production.

CORN STOVER YIELDS

Corn stover is important as roughage over the portion of the Great Plains that is better adapted to corn than sorghums. In areas where winter feed supplies are more adequate, corn stover is often regarded as a by-product of producing ear corn and not as a thing of value in itself. In the Great Plains, however, particularly in dry years, corn stover is one of the surest annual feed crops and is valued accordingly. The stover yields in pounds per acre from this experiment are presented in Table 3.

The highest average stover yield was 2,160 pounds per acre from the plants spaced 12 inches in the 44-inch rows. From this maximum, the yields from the other 44-inch row spacings decreased as the

TABLE 3.—*Stover yield of corn from five spacings in 44-inch rows and one spacing in 88-inch rows at the Akron, Colo., field station for the 12-year period 1924–1935, inclusive.**

Planned spacing, inches	Yield per acre, pounds												Average yields, pounds		
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	All years	3 good years, 1927, 1929, and 1930	Other 9 years
								44-inch Rows							
12	1,345	1,178	2,967	2,950	2,986	3,700	3,623	825	1,680	2,320	233	2,113	2,160	3,424	1,739
18	2,047	1,323	3,260	2,460	2,676	2,880	3,154	786	1,691	2,073	267	1,843	2,038	2,831	1,774
24	1,250	1,385	2,913	1,753	2,276	2,960	3,117	925	1,177	1,973	267	1,527	1,794	2,610	1,521
30	1,143	1,116	2,280	1,747	1,783	2,490	2,365	711	1,291	1,467	333	1,553	1,523	2,201	1,297
36	800	1,240	2,060	1,350	1,533	2,310	2,090	773	1,236	1,640	233	1,600	1,405	1,917	1,235
Average	1,317	1,248	2,696	2,052	2,251	2,868	2,870	804	1,415	1,895	267	1,727	1,784	2,597	1,513
								88-inch Rows							
12	670	1,261	1,567	1,080	1,601	1,200	1,326	873	1,086	1,513	367	1,730	1,190	1,202	1,185

*Yields are the average of three replications, except in 1929 when the second and third replications only are used.

plant population per unit area was decreased. In the double-spaced row plat the population was about equal to that in the 30-inch spacing in 44-inch rows, but the average yield was even lower than that from the 36-inch spacing.

The individual years, aside from the three good producing ones, did not show any consistently regular increase or decrease of the stover yield from the thick to the thin populations, but the general trend of yields were decidedly downward as the population was decreased, as the 12-year and the 9-year averages reveal. There were only 2 of the 9 years, 1928 and 1933, when the trend was regularly downward from the thick to the thin populations.

When the 3 good producing years and the 9 less productive years were averaged separately, it was found that all spacings, as was the case with grain, produced higher yields in the 3 years than in the 9-year period. The 3-year averages for stover decreased regularly as the plant population per unit area decreased, indicating again the complete dependence of yield on thick population whenever ample moisture is available.

The trend of the stover yield in the 9-year average was downward as the population per unit area was decreased, whereas that of the grain was upward, indicating that the corn did not curtail the production of stover in favor of that of grain when ample moisture was not available for both. The growth of individual plants tended to remain uniform over the various spacings. The thinner populations did not produce increased stover, and hence there was more soil moisture available for grain.

The double-spaced row method failed as signally in stover as in grain production. In neither the averages of all 12 years, the 3 good-producing years, or the 9 other years, did the double spaced plat produce as much stover as the 30-inch spaced plants in the 44-inch rows, where the plant population per unit area was practically the same.

When the averages of the five 44-inch row plats were compared for the 3 good producing and the 9 other years, it was found that the stover production was only 72% higher in the good years, whereas the grain production was 421% higher. This indicates that adequate stalks were produced practically every year, but that they were not always able to produce ears because of lack of available moisture at the tasseling and silking stage of development. The thinner populated plats were able to produce some grain in the adverse years because less soil moisture was used in growing a lesser number of stalks to the nearly uniform height reached. The uncertainty of rainfall at, or immediately preceding, the critical stage of development appears to be the limiting factor in corn grain production in this region. In only two years, 1931 and 1934, was the stover development so low as to cause doubt as to its ability to produce grain.

Because there was no appreciable difference in the height of the corn on various spacings, no measurements were made prior to 1928. Height notes since 1928 have largely confirmed that early observation. There were no differences in height in 1928, 1929, 1930, 1934, and 1935. There was a slight increase in plant height from the 12- to the 36-inch spaced plats in 1931, 1932, and 1933. This average increase in

height for the 3 years was about 1 inch for each 6-inch increase in the plant spacing, and averaged 5 inches between the 12- and the 36-inch spaced plants. This indicates again that the first result of the season's rainfall is to produce stover, and that stover production is not sacrificed to conserve moisture for the later production of grain. Moisture must be available at and after tasseling, if grain is to be produced.

Corn never reaches high stature in this section. The crop reached a height of 72 inches in 1928, which is tall for this section, but this was one of the low grain-producing years. The crop averaged 56 inches in 1929 and 52 inches in 1930. These were both high grain-producing years. The crop reached a height of 51 inches in 1933, but this was a year of low grain production.

There appears to be little correlation between stalk height and either grain or stover production. The average height of corn over the 8-year period of 1928–35 was 52 inches. It appears that a fair grain yield can be realized on a stalk 42 inches in height, which was the height of the crop in 1932, but that stalks generally grow taller whether or not they produce grain. The better yields were obtained on stalks about 54 inches high, still very short corn.

If corn were to be grown for forage alone, a thicker planting rate than for grain production should be recommended. However, corn is seldom grown for stover alone in this region, because sorgo, an equally desirable feed, outyields it sharply in the same crop sequences.

TOTAL CORN YIELDS

The total combined production of grain and stover by years is shown in Table 4. The highest producing year was 1930 with an average yield of 5,572 pounds per acre from the five 44-inch spaced plat. This was likewise the year of highest grain production. The most productive spacing for both grain and stover that year was the 12-inch spaced plants in the 44-inch rows.

The rate of planting resulting in the highest total weight for the 12-year period was the 12-inch spacing in 44-inch rows. The method resulting in the highest grain yield, it will be recalled, was the 24-inch spacing. Thus there is again noted the tendency of corn to produce stover first. Whether or not grain is produced depends upon the supply of moisture available after the stalk has been formed. There was a regular decrease in the total yield of the 44-inch row plats as the plant population per unit area was decreased.

The 9-year averages show a smaller yield from the 12-inch than from the 18-inch spacings, indicating that there may have been some dwarfing of plants from too much competition for moisture. The 7-year average heights were 49 inches for the 12-inch spacing and 51 inches for the 18-inch spacing. The observed dwarfing during adverse years was more apparent in girth than in height of plants, the thickly planted corn appearing more spindling.

The average of the 3 good producing years is outstandingly higher than that for the 9 other years for each spacing. When ample moisture is available, both stover and grain yields are benefited. The highest total yields are on the most thickly populated plats.

Double spacing the rows failed to benefit the total yield. The 12-year average total production from this method was only 75% of that from plants spaced 30 inches in 44-inch rows. The average height of the plants was the same as for the 24-, 30-, and 36-inch spaced plants in the regulation width rows.

The averages of total production indicate that where corn in this region is grown for silage, it should be planted thicker than where intended for grain production. The recommended rate is 12 to 18 inches between the plants in 44-inch rows. This corn would make silage containing about 20% of grain.

PERCENTAGE OF GRAIN IN TOTAL CORN YIELD

The percentage of ear corn in the total yield for each spacing each year, and averages for the 12 years, the 3 good producing years, and the 9 other years are shown in Table 5.

The 12-year averages show the lowest percentage of ear corn, 19.2, to be on the 12-inch spaced plants in 44-inch rows. As the space between plants was increased, ear corn percentages increased regularly, and consequently those of the stover decreased. In the 36-inch spacing in the 44-inch rows the percentage of ear corn was 31.5 and that of stover 68.5. This again indicates the strong tendency of corn to produce stover first and grain second It also shows that after a certain stover stature was reached, any additional available moisture remaining in the thinner plantings went to the development of a greater grain yield.

The 9-year average showed the same trend as the 12-year, but the percentage of grain was lower in all spacings.

The average of the 3 good producing years showed the same trend, but the percentage of grain was much higher and the variation from the 12- to the 36-inch spaced plants was much smaller. The percentage of grain in good years was approximately the same when the plants were spaced over 24 inches in the row. The highest percentage of grain in any single year was 55.2 in the 24-inch spaced plants in 44-inch rows in 1927.

The proportion of grain to stover in the double-spaced row plat was about the same as the average of the 30- and 36-inch spacings in the 12-, 9-, and the 3-year averages.

Corn seeded 30 to 36 inches apart in regulation width, 44-inch rows, in this section will average about 30% ear corn by weight; that seeded 12 to 18 inches apart in regulation 44-inch rows will average about 20% ear corn; while that seeded 24 inches apart in regulation 44-inch rows will average about 25% ear corn.

WINTER WHEAT GRAIN YIELDS

The winter wheat yields in bushels per acre, following the different spacings of the previous crops of corn, are shown in Table 6. The year 1927 was the first when a full crop of wheat was harvested from this experiment. In 1925 the crop was so unevenly damaged by army cutworms that comparable yields between the different plats could not be obtained. In 1926 the crop was so unevenly damaged by winter-

TABLE 4.—*Total yield of corn (grain and stover) from five spacings in 44-inch rows and one spacing in 88-inch rows at the Akron, Colo., field station for the 12-year period 1924–1935, inclusive.**

Planned spacing, inches	Yield per acre, pounds												Average yield, pounds		
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	All years	3 good years, 1927, 1929, and 1930	Other 9 years
							44-inch Rows								
12	1,534	1,178	3,772	5,827	3,154	6,003	6,507	902	2,219	2,495	233	2,631	3,038	6,112	2,013
18	2,236	1,323	4,072	4,798	3,005	5,001	6,101	898	2,475	2,360	267	2,459	2,916	5,300	2,122
24	1,565	1,385	3,802	3,916	2,941	4,850	6,064	1,037	2,143	2,519	267	2,185	2,723	4,943	1,983
30	1,661	1,116	3,267	3,721	2,539	4,254	4,822	830	2,173	2,118	333	2,407	2,437	4,266	1,827
36	1,465	1,240	2,970	2,827	2,296	3,801	4,372	899	2,174	2,347	233	2,594	2,268	3,667	1,802
Average	1,695	1,248	3,578	4,215	2,790	4,779	5,572	916	2,234	2,371	267	2,455	2,677	4,855	1,950
							88-inch Rows								
12	1,237	1,261	2,190	2,046	2,273	2,376	2,649	964	1,751	2,185	367	2,668	1,831	2,357	1,655

*Yields are the average of three replications, except in 1929 when the second and third replications only were used

TABLE 5.—*The percentage of ear corn in the total yields of corn in five spacings in 44-inch rows and one spacing in 88-inch rows at the Akron, Colo., field station for the 12-year period 1924–1935, inclusive.*

Planned spacing, inches	Percentage of grain in total												Average percentage		
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	All years	3 good years, 1927, 1929, and 1930	Other 9 years
							44-inch Rows								
12	12.3	0	21.3	49.4	5.3	38.4	44.3	8.5	24.3	7.0	0	19.7	19.2	44.0	10.9
18	8.5	0	19.9	48.7	10.9	42.4	48.3	12.5	31.7	12.2	0	25.1	21.7	46.5	13.4
24	20.1	0	23.4	55.2	22.6	39.0	48.6	10.8	45.1	21.7	0	30.1	26.4	47.6	19.3
30	31.2	0	30.2	53.1	29.8	41.5	51.0	14.3	40.6	30.7	0	35.5	29.0	48.5	23.6
36	45.4	0	30.6	52.2	33.2	39.2	52.2	14.0	43.1	30.1	0	38.3	31.5	47.9	26.1
Average	23.5	0	25.1	51.7	20.4	40.1	48.9	12.0	37.0	20.3	0	29.7	25.6	46.9	18.7
							88-inch Rows								
12	45.8	0	28.4	47.2	29.6	49.5	49.9	9.4	38.0	30.8	0	35.2	30.3	48.9	24.1

killing and spring soil blowing that for the second successive time comparable yields were impossible to obtain. The 1934 seeding for the 1935 crop completely winterkilled and the land was spring seeded to oats without regard to the plat lines. The year, however, is used in the averages as a complete failure.

Averages for all 9 years, for the 3 good producing years, and for the 6 other years showed yields that were nearly uniform for all plats seeded on 44-inch corn rows. There was no pronounced upward or downward trend, but there was a slight indication of an upward trend in the average yields as the plant population of the previous crop of corn became less. This is found in a comparison between the yield from the two thinnest with that from the two thickest populated plats. The average yield of wheat on the 24- and 30-inch spacings was higher than the average of wheat on the 12- and 18-inch spacings for all three groups of years.

This seems to indicate quite clearly that, while there is no well-defined, regular trend, a little something beneficial to wheat grain production remains in the soil of the more thinly populated plats after the corn has been matured. Since moisture is always the limiting factor in this soil, it seems logical to attribute the difference to soil moisture. The average total production of corn was materially less from the two most thinly populated plats, thus theoretically leaving moisture or some vital plant nourishing element in the soil for the benefit of the following crop

Wheat production from the five regularly spaced corn plats was 5.4 times greater during the good than during the low producing years.

The double-spaced corn land produced a greater yield of winter wheat than the average of the five regularly spaced plats, in the 9 years, in the 3 good producing years, and in the 6 other years. These double-spaced corn plats produced less ear corn. The increase in wheat grain over the whole period was 18%, while the decrease in ear corn was 28%. This appears to indicate a less efficient use of soil moisture when wide-spaced corn rows are used in rotation with winter wheat. The increase of 2 bushels per acre in wheat yield following corn in double-spaced rows was more than compensated for by a decrease of 3.6 bushels of ear corn and 594 pounds of corn stover.

The double-spaced corn land added very little to the certainty of the production of winter wheat. The yields following double-spaced corn were low whenever yields following regularly spaced corn were low.

A comparison between the yield of winter wheat on double-spaced corn land and that on fallowed land is not directly obtainable. The winter wheat grown on fallowed land closest to this experiment was in the winter wheat variety experiment where Turkey C. I. 1571 is no longer grown. Kanred, which yields approximately 1.5 bushels more per acre, averaged 20 bushels per acre on fallow in the variety experiment during the period from 1927 to 1936, with the yield of 1930 excluded. The double-spaced corn land produced approximately 64% as many bushels of winter wheat over this period as fallowed land.

WINTER WHEAT STRAW YIELDS

The straw yields in pounds per acre from the differently populated corn plats for each year are shown in Table 7. There was little difference in the weights of straw following the different spacings in regular width rows, although the two thinnest populated corn plats produced slightly more straw than the two thickest during the 9-year period.

The winter wheat was nearly uniform in height on the variously spaced corn plats, throughout the period of this experiment. The shortest wheat was on the 44 by 12 inch spaced corn plats. The 8-year average height was 24.5 inches. The tallest was on the plats where corn was spaced 44 x 36 and 88 x 12 inches, where the average height was 25.5 inches.

The double-spaced corn plats produced 178 pounds more straw per acre than the average of the five regularly spaced plats over the 9-year period.

TOTAL YIELD OF CORN AND WHEAT

The chief interest in total yields, particularly those of winter wheat, is in studying soil moisture carry-over from corn. Accordingly, the total corn yields and the total yields of the following crops of wheat are assembled for the period when wheat yields were obtained. The year 1929 is not used for corn in this table because the corn preceded the wheat crop of 1930 which was omitted from the tables.

The total annual winter wheat yields from the variously spaced corn plats and the yields of the preceding corn crops are shown in Table 8. The total yields of winter wheat, like those of grain and straw, were nearly uniform and were lacking in any regularly gradated response to different spacings of previous crops of corn. There was, however, a small difference in yield in favor of the thinner spacings.

During the 9-year period, the two thinnest 44-inch row corn plats produced 94 pounds more of wheat, but 625 pounds less of corn than the two thickest. The loss in combined total corn and wheat from these two thinly populated plats was 531 pounds. The double-spaced corn land produced 230 pounds more of wheat but 486 pounds less of corn than the average of the two thinnest spacings in regular width rows.

During the two good producing corn years included in this table, 1927 and 1930, the average total yield of corn on the two widest spacings in 44-inch rows was 1,873 pounds lower than on the two closest spacings, but the average total yield of the following wheat crops, 1928 and 1931, was 475 pounds higher. Evidently the moisture left in the soil by the thinner spacings of corn was sufficient to increase materially the yield of wheat at the expense of a heavy decrease in corn yield. During the same years the yield of corn in the double-spaced rows averaged 1,588 pounds less than in the two widest spacings in 44-inch rows, and the following crops of wheat averaged 1,035 pounds higher. A portion of the land between the corn rows must have approached the condition of bare fallow in such years. Comparing the 44 x 12 inch and the double row spacings for the two pro-

TABLE 6.—*Grain yields of winter wheat following corn from five spacings in 44-inch rows and one spacing in 88-inch rows at the Akron, Colo., field station for the 10-year period from 1927–1936, inclusive.*

Planned spacing, inches	Yield per acre, bushels										Average yields, bushels		
	1927	1928	1929	1930*	1931	1932	1933	1934	1935	1936	All years	3 good years, 1927, 1929, and 1930	Other 6 years
						44-inch Rows							
12	25.1	19.2	4.1	—	8.7	5.6	3.8	1.8	0	23.2	10.2	22.5	4.0
18	25.1	21.8†	4.3	—	7.7	5.3	4.1	1.8	0	22.9	10.3	23.3	3.9
24	25.7	24.0	4.9	—	8.9	5.4	5.0	2.1	0	23.2	11.0	24.3	4.4
30	24.9	24.8	5.1	—	9.1	5.9	4.7	2.0	0	21.3	10.9	23.7	4.5
36	26.2	27.4	6.0	—	10.2	7.1	5.1	2.2	0	21.4	11.7	25.0	5.1
Average	25.4	23.4	4.9	—	8.9	5.9	4.5	2.0	0	22.4	10.8	23.8	4.4
						88-inch Rows							
12	23.8	34.4	5.6	—	13.7	7.3	4.6	2.2	0	23.4	12.8	27.2	5.6

*Only two replications were planted in the fall of 1929 on regularly spaced plats. Two of these plats were mixed in thrashing. Individual yields from the single replication were not representative. The average yield of the entire block was 23.9 bushels per acre.
†Yields on the 44 x 12 inch and 44 x 18 inch spacings in 1928 were reduced by soil blowing.

TABLE 7.—*Straw yields of winter wheat following corn grown in five spacings in 44-inch rows and one spacing in 88-inch rows at the Akron, Colo., field station for the 10-year period 1927–1936, inclusive.*

Planned spacing, inches	Yield per acre, pounds										Average yields, pounds		
	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	All years	3 good years, 1927, 1928, and 1936	Other 6 years
						44-inch Rows							
12	3,307	2,181	356	—	747	1,100	560	823	0	3,043	1,346	2,844	598
18	2,893	2,623	686	—	703	947	553	423	0	2,893	1,302	2,803	552
24	2,760	2,660	506	—	668	980	627	373	0	2,577	1,239	2,666	526
30	3,107	2,679	695	—	653	1,080	580	547	0	2,453	1,310	2,746	593
36	3,160	3,021	628	—	955	1,173	640	570	0	2,450	1,400	2,877	661
Average	3,045	2,633	574	—	745	1,056	592	547	0	2,683	1,319	2,787	586

TABLE 8.—*Total acre yields in pounds of corn in designated spacings and of winter wheat following corn in those spacings for the years 1926–1936, inclusive.*

Year and crop	Spacings of corn plants, inches					
	44 x 12	44 x 18	44 x 24	44 x 30	44 x 36	88 x 12
1926 corn	3,772	4,072	3,802	3,267	2,970	2,190
1927 wheat	4,813	4,399	4,302	4,601	4,732	4,468
1927 corn	5,827	4,798	3,916	3,721	2,827	2,046
1928 wheat	3,333	3,931	4,100	4,167	4,665	5,717
1928 corn	3,154	3,005	2,941	2,539	2,296	2,273
1929 wheat	602	944	800	1,001	988	849
1930 corn	6,507	6,101	6,064	4,822	4,372	2,649
1931 wheat	1,269	1,165	1,202	1,199	1,567	2,152
1931 corn	902	898	1,037	830	899	964
1932 wheat	1,436	1,265	1,304	1,434	1,599	1,585
1932 corn	2,219	2,475	2,143	2,173	2,174	1,751
1933 wheat	788	799	927	862	946	899
1933 corn	2,495	2,360	2,519	2,118	2,347	2,185
1934 wheat	931	531	499	667	702	719
1934 corn	233	267	267	333	233	367
1935 wheat	0	0	0	0	0	0
1935 corn	2,631	2,459	2,185	2,407	2,594	2,668
1936 wheat	4,435	4,267	3,969	3,731	3,734	3,981
Average for all years:						
Corn	3,082	2,937	2,764	2,468	2,301	1,899
Wheat	1,956	1,922	1,900	1,962	2,104	2,263
Total	5,038	4,859	4,664	4,430	4,405	4,162
Average for two years:*						
1927, 1930: Corn	6,167	5,450	4,990	4,272	3,600	2,348
1928, 1931: Wheat	2,301	2,548	2,651	2,683	3,116	3,935
Total	8,468	7,998	7,641	6,955	6,716	6,283
Average for 7 other years:						
Corn	2,201	2,219	2,128	1,952	1,930	1,771
Wheat	1,858	1,744	1,686	1,757	1,814	1,786
Total	4,059	3,963	3,814	3,709	3,744	3,557

*The 2-year averages are for the years of highest total corn production and the following crops of wheat.

ductive corn years, it is seen that an increase of 1,634 pounds in the total weight of wheat on the double-spaced rows followed a loss of 3,819 pounds in the total weight of corn.

During the 7 years following poor or medium crops of corn the average yield of wheat in the two wider corn spacings in 44-inch rows was 1,786 pounds per acre, while that in the two closer spacings was 1,801 pounds. This demonstrates clearly that in years when corn suffered from drouth there was no reserve moisture available to wheat left in the wider spaced plantings. The average corn yield during the

7 years was 269 pounds higher in the two closer than in the two wider spacings. In these adverse years, wide spacing of plants in the row decreased the total weight of corn without increasing the total weight of the wheat crop following.

During the same 7 years the yield of corn in double-spaced rows was 170 pounds lower than the average yield of corn in the two widest spacings in regular width rows. The average yield of the following wheat crops was exactly equal. Growing corn in double width rows reduced the yield of corn in years of low production without increasing the yie'd of the following crop of wheat.

It is thus seen that the soil between double-spaced corn rows assumes the status of a partial fallow in years of ample rainfall only. In less favorable years double-spaced corn uses all or practically all the available water.

The total yield of corn and wheat decreased as the spacings increased. This was true for the average of all years.

TOTAL GRAIN YIELDS OF CORN AND WHEAT

The yields of ear corn and the grain yields of the following wheat crops are shown in Table 9. The results are much the same as with total weights, but there are some differences. For the 9 years shown, the yield of ear corn was slightly the highest in the 24-inch spacings with the yield decreasing as the plant population was increased or decreased. This is in distinct contrast with the total weights of corn, which were highest in the 12-inch spacing and decreased regularly as the plant population was decreased. The yields of wheat following the different spacings increased as the plant population of the preceding corn crop decreased. The greatest combined total bushels of corn and wheat was in the 44 x 24 inch spacing, but the combined yields in the 44 x 30 and the 44 x 36 inch spacings were only slightly lower. The total grain production of wheat and corn on double-spaced corn land was lower than for any spacing in regular width rows.

For the two good corn-producing years, the average yield of ear corn decreased regularly from 41.2 bushels per acre on the 12-inch spacing in 44-inch rows to 16.4 bushels in double width rows. The yields of wheat following the corn increased as regularly as the corn yields decreased, but the magnitude of the changes was smaller. The wheat following double-spaced corn produced a yield 10.1 bushels per acre higher than that of wheat following corn planted 12 inches apart in 44-inch rows. The loss in yield incurred in growing corn in the wide spacing was 24.8 bushels per acre. In these two good producing corn years, the maximum combined yield of wheat and corn was on the closest corn spacing and the yields decreased as the plant population of the corn decreased. The difference in yield between the 12- and 24-inch spacings, however, was not great enough to recommend the 12-inch spacing for corn even in good years.

In the 7 poor corn years, the maximum yield of corn grain was on the 36-inch spacing in regular width rows, and the yields decreased as the plant population was increased. This is the opposite of the total yield of corn which was highest on the closest spacings. The aver-

TABLE 9.—*Yields in bushels per acre of ear corn in planned spacings and of winter wheat following corn on those spacings for the years 1926–1936, inclusive.*

Year and crop	Spacings of corn plants, inches					
	44 x 12	44 x 18	44 x 24	44 x 30	44 x 36	88 x 12
1926 corn	11.5	11.6	12.7	14.1	13.0	8.9
1927 wheat	25.1	25.1	25.7	24.9	26.2	23.8
1927 corn	41.1	33.4	30.9	28.2	21.1	13.8
1928 wheat	19.2	21.8	24.0	24.8	27.4	34.4
1928 corn	2.4	4.7	9.5	10.8	10.9	9.6
1929 wheat	4.1	4.3	4.9	5.1	6.0	5.6
1930 corn	41.2	42.1	42.1	35.1	32.6	18.9
1931 wheat	8.7	7.7	8.9	9.1	10.2	13.7
1931 corn	1.1	1.6	1.6	1.7	1.8	1.3
1932 wheat	5.6	5.3	5.4	5.9	7.1	7.3
1932 corn	7.7	11.2	13.8	12.6	13.4	9.5
1933 wheat	3.8	4.1	5.0	4.7	5.1	4.6
1933 corn	2.5	4.1	7.8	9.3	10.1	9.6
1934 wheat	1.8	1.8	2.1	2.0	2.2	2.2
1934 corn	0	0	0	0	0	0
1935 wheat	0	0	0	0	0	0
1935 corn	7.4	8.8	9.4	12.2	14.2	13.4
1936 wheat	23.2	22.9	23.2	21.3	21.4	23.4
Average for 9 years:						
Corn	12.8	13.1	14.2	13.8	13.0	9.4
Wheat	10.2	10.3	11.0	10.9	11.7	12.8
Total	23.0	23.4	25.2	24.7	24.7	22.2
Average for 2 years:*						
1927, 1930: Corn	41.2	37.8	36.5	31.7	26.9	16.4
1928, 1931: Wheat	14.0	14.8	16.5	17.0	18.8	24.1
Total	55.2	52.6	53.0	48.7	45.7	40.5
Average for other 7 years:						
Corn	4.7	6.0	7.8	8.7	9.1	7.5
Wheat	9.1	9.1	9.5	9.1	9.7	9.6
Total	13.8	15.1	17.3	17.8	18.8	17.1

*The 2-year averages are for the years of highest total corn production and the following crops of wheat.

age yield of corn in double width rows in unfavorable years was lower than the yield of any corn spaced wider than 18 inches in regular width rows. The average yields of wheat following the seven poor crops of corn varied very little, though there was a suggestion of a slight upward trend with the thinner corn stands. Any possible increase in the yield of wheat was not great enough to be a factor in determining the best spacing for corn. In the years when corn was injured by drouth, little or no moisture available for wheat was left on even the thinnest spacings.

The total grain yield of corn and wheat while differing slightly in favor of the wide spacing did not differ enough to make it advisable to recommend a spacing wider than 24 inches. The close spacing was noticeably lower in total grain yield.

SUMMARY

A 2-year rotation of corn and winter wheat at Akron, Colo., was used to determine the effect of different spacings of corn on the yield of the corn and the following wheat crop.

Twelve crops of corn were grown from 1924 to 1935, inclusive, and nine crops of winter wheat. Failure to obtain stands through winter-killing and insect injury accounted for the loss in winter wheat crops.

The highest 12-year average yield of ear corn was 13.3 bushels per acre for 24-inch spaced plants in 44-inch rows. This spacing is recommended for grain production for conditions similar to those found at Akron.

The 12-year average yield of 9.2 bushels per acre of ear corn from the double-spaced rows, was 28% less than the average for five spacings in the 44-inch row plats.

The highest total corn yield, 3,038 pounds per acre, was from the 12-inch spacing in 44-inch rows. The yield from the 18-inch spacing was only a little lower. From 12 to 18 inches in 44-inch rows is recommended as a spacing for silage production in this locality.

Corn seeded 30 to 36 inches apart in 44-inch rows averaged about 30% ear corn by weight. That seeded 12 to 18 inches apart in 44-inch rows averaged about 20% ear corn. That seeded 24 inches apart in 44-inch rows averaged about 25% ear corn.

The highest average yield of winter wheat for grain was 12.8 bushels per acre obtained from double-spaced row corn land. This was 2 bushels per acre higher than the average of the five spacings in 44-inch rows.

There was a loss in ear corn production of 3.6 bushels per acre when the double-spaced row plat was compared with the average for the five spacings in the 44-inch rows. The gain in wheat yield did not more than compensate for the loss in corn.

Planting corn in double-spaced rows decreased yields markedly in years of good production and did not increase the sureness of production in poor years. There was not a single adverse year when the yield of double-rowed corn equalled that of thin-spaced corn in regular width rows.

The greatest total production of ear corn and wheat grain was obtained from land where corn plants were spaced 24 inches apart in 44-inch rows.

The greatest total weights of corn and wheat (grain, stover, and straw) were obtained from the 12-inch spaced corn in 44-inch rows.

ALFALFA INHERITANCE STUDIES IN NEW JERSEY[1]

GLENN W. BURTON[2]

THE need of new alfalfa strains capable of maintaining stands and making satisfactory growth upon the heavier podsolic soils of New Jersey led to the study described here. It was believed that if the hardiness and well-branched type of root system characteristic of certain *Medicago falcata* L. plants might be combined with the yield capacity of some of the *M. sativa* L. group through species hybrids, strains superior for this region might be obtained. With this thought in mind a number of hybrids were made in the spring of 1932 between a *M. falcata* L. plant possessing the desired characters mentioned above and typical individuals of several *M. sativa* L. varieties.

F_1 plants were grown in buckets of soil in the greenhouse and seed of the two most promising individuals was harvested for further study. The striking differences between the parents of the *M. falcata* L. X Hairy Peruvian hybrid, shown in Table 1, made the study of the behavior of this cross in advanced generations seem highly desirable.

TABLE 1.—*Characteristics of the M. falcata L. X Hairy Peruvian hybrid parents.*

Character studied	Hairy Peruvian	*M falcata*
Yield capacity	High	Low
Root type	Distinct tap	Well-branched
Plant height	Tall	Short
Time of blooming	Early	Late
Flower color	Purple	Yellow
Leaf index $\left(\frac{\text{Width x 100}}{\text{length}}\right)$	39.8	80.9
Leaf size (width x length)	271	138

In the fall of 1933, 100 1-gallon stone jars were filled with an equivalent of 4 kilograms of dry screened soil taken from the surface 6 inches of a heavy Sassafras gravelly loam which was low in available nutrients (Morgan's method) and which had a pH of 5.6. Heat scarified seed of the F_1 *M. falcata* L. X Hairy Peruvian hybrid was planted in these pots and the seedlings were thinned in an unbiased manner to one per pot. Moisture content of the soil was maintained at about 80% of saturation by bringing the pots up to weight with water additions at regular intervals.

Field plantings of the F_2 progenies of this hybrid and of a *M. falcata* L. X Hardigan hybrid were made in the spring of 1934 by starting the seedlings in 2-inch paper pots in the greenhouse and setting them out in the field when about 6 weeks old. Soil from this field which was

[1]Journal series paper, New Jersey, Agricultural Experiment Station, Department of Agronomy. Received for publication March 20, 1937.

[2]Agent, U. S. Dept. of Agriculture, Tifton, Georgia; formerly Research Assistant at the New Jersey Agricultural Experiment Station. The writer wishes to express his appreciation to Dr. H. B. Sprague, head of the Department of Agronomy of Rutgers University, who offered advice and constructive criticism during the progress of these investigations.

known to be unsuited for alfalfa production was used in all greenhouse studies and is described above.

The striking variations found in the F_2 progeny of the *M. falcata* L. X Hairy Peruvian cross growing under carefully controlled conditions in the greenhouse are demontrated in Fig. 1.

FIG. 1 —F_2 plants of the *M. falcata* L. X Hairy Peruvian hybrid grown in the greenhouse.

Three yield determinations were made, the first when most of the plants were beginning to bloom, the second after most of the plants had matured a seed crop, and the third when the plants were beginning to bloom again. It was recognized that with a perennial plant such as alfalfa three such yield determinations would hardly be indicative of the exact yield capacity of any one plant as compared with others in the same progeny. It was believed, however, that the relative yields of the plants would not change enough to alter greatly the correlation values presented in Table 2.

Measurements were made of a large number of morphological characters, many of which seemed to show no relation to yield. Those characters of most interest with their relation to plant yield expressed in correlation ratio values are presented in Table 2.

Plant height and the number of stems per plant were determined at the time of harvest. Ten representative mid-leaflets were measured and averaged to give the leaf index $\left(\frac{\text{width x 100}}{\text{length}}\right)$, an expression of leaf shape, and leaf size (width x length). Leaves were separated by hand from the oven-dried material of the third harvest and their percentage by weight was calculated for each plant to give the characteristic "per cent of leaves". Date of blooming was recorded prior to the second or seed harvest. The milligrams of seed produced per plant were obtained at the second harvest. After the third harvest, the roots were easily separated from the dry soil as it was taken from the pots and were classified into five groups ranging from group 1 with a distinct tap root to group 5 with a well-branched type of root system.

The marked variability in color of the flowers of the F_2 progeny of both hybrids studied made the explanation of its inheritance on the basis of phenotypic counts impossible. The number of pure yellow-flowered individuals, however, indicates that this character is controlled by three factors. The near approach to the normal made by

TABLE 2.—*Correlation ratios and regression types between plant yields and various morphological characters in alfalfa.**

Character studied	Plant yield	F_2 *M. falcata* X Hairy Peruvian		F_2 *M. falcata* X Hardigan in field	Commercial Kansas common in field
		Greenhouse	Field		
Population		100	285	540	80
Stem length of 6-weeks old plants	1st	+.49 N	——	——	——
	2nd	+.65 N	——	——	——
	3rd	+.71 N	——	——	——
Plant height	1st	+.67 L	+.25	——	+.42 L
	2nd	+.63 N	+.51 L	——	+.73 L
	3rd	+.61 L	+.55 L	——	+.78 L
Number of stems per plant first harvest	1st	+.48 N	——	——	——
	2nd	+.56 N	——	——	——
	3rd	+.54 N	——	——	——
Leaf index (width x 100) / length	1st	-.44 L	-.22	——	00
	2nd	-.33	-.34 L	——	00
	3rd	-.57 L	-.58 L	——	00
Leaf size (width x length)	1st	+.68 L	+.30 N	——	00
	2nd	+.60 N	+.46 N	——	00
	3rd	+.61 N	+.50 N	——	00
Per cent of leaves third harvest	1st	.36	00	——	.44 N
	2nd	.70 N	00	——	.34 N
	3rd	.52 N	00	——	.55 N
Date of blooming	1st	+.57 N	——	+.37 L	——
	2nd	+.66 N	——	——	——
	3rd	+.40 N	——	——	——
Flower color	1st	00†	00	00	——
	2nd	00	00	00	——
	3rd	00	00	00	——
Seed yield	1st	+.38	——	——	——
	2nd	+.61 N	——	——	——
	3rd	+.53 N	——	——	——
Root type	1st	+.48 N	——	+.27 L	——
	2nd	+.42 N	——	——	——
	3rd	+.62 N	+.34 L	——	+.35

*L = linear regression N = non-linear regression. All correlation ratio values accompanied by regression type symbols N or L are considered significant, the odds being at least 30 to 1 that the occurrence of such relationships could not be due to chance alone.

the distribution curves of all other characters considered in Table 2 suggests that the expression of these characters is governed by a number of genetic factors.

The correlation ratio was used to measure the relation existent between yields and morphological characters when regression was nonlinear. Since the correlation ratio and correlation coefficient give simi-

lar values when regression is linear, it seemed desirable to use the correlation ratio exclusively in measuring relationships and to include regression symbols, L and N, in the table to indicate linearity. Probable error values, for the sake of simplicity, were omitted from Table 2, significance being cared for in a table footnote.

The higher correlation ratio values obtained between yields and the various characters in the greenhouse is explainable in part by the more uniform environment in the greenhouse and by the disturbing effect of transplanting upon the expression of root type in the field progenies.[3] Slight injury by rabbits to certain individuals influenced to some degree the validity of field results. When appreciable injury occurred, no attempt was made to use the data obtained in correlations.

The high magnitude of the near-linear relation found between stem length of seedlings and plant yields suggests that this character might be used to eliminate a large number of inferior plants at the time when they would normally be set out in the field. While additional data are required to substantiate these results, it would seem that one might easily discard the smaller half of his population at 6 weeks of age (germination being uniform) and lose very few plants having outstanding yield capacity.

The highly significant linear or near-linear correlations obtained between plant yields and height at the time of cutting indicate that the tall plants are usually superior in yield capacity.

The positive correlation obtained between yields and the number of stems per plant suggests that the heavier plants tend to have more stems. A number of plants having a large number of stems were intermediate in yield capacity causing the regression to be non-linear.

That considerable linkage exists between the genetic factors determining yield and leaf size and shape in the progeny of the *M. falcata* L. X Hairy Peruvian hybrid is apparent in the type and magnitude of the correlations obtained between these characters. The negative linear correlation ratio values indicate that the low-yielding F_2 plants tend to have the more nearly round leaves characteristic of the low-yielding *M. falcata* L. parent. The significant positive relations between yield and size of leaf, although slightly curvilinear, demonstrates that the large leaves and high yield capacity of the Hairy Peruvian parent tend to occur together in advanced generations. That this association between high yield of plant and large oval leaves is confined largely to this hybrid involving very different parents is shown by the lack of any correlation between yield and leaf characters in 80 commercial Kansas common plants. Thus it seems that the use of leaf characters in the choice of high-yielding individuals within common varieties would not be fruitful.

The occurrence of a significant relation and a very similar but unusual type of regression between plant yield and percentage of leaves in both the greenhouse F_2 progeny of the *M. falcata* L. X Hairy Peruvian hybrid and the commercial Kansas common plants was interesting. In both populations the highest and lowest yielding plants possessed relatively few leaves, while the group of plants intermediate in

[3]Garver, Samuel. Alfalfa root studies. U. S. D. A. Bul. 1087. 1926.

yield capacity possessed the highest percentage of leaves. These results suggest that considerable difficulty would accompany the selection of individuals possessing both high yield capacity and high leaf percentage, and that very large populations would be required if the efforts made in this direction were to attain any appreciable measure of success. The lack of a significant correlation between yield and percentage of leaves in the field F_2 progeny of the *M. falcata* L. X Hairy Peruvian hybrid may be due in part to the unusual type of slow growth made by these plants late in the fall when leaf percentages were determined. It is believed that the results obtained in the greenhouse under carefully controlled conditions are more indicative of the true relationship between these characters.

It is apparent from the positive linear or near-linear correlations obtained between plant yields and date of blooming that the larger plants tend to bloom earlier than the smaller ones.

As Table 2 indicates, no significant relation was found between plant yield and flower color. The yellow-flowered F_2 progeny gave a mean yield very similar to that of the purple-flowered plants in the same population.

Although the relation was not linear, there was a marked tendency for the largest plants to produce the greatest quantity of seed as the correlation ratio values in Table 2 show. It is recognized that since most of the flowers in the greenhouse were tripped artificially that this same relation might not occur under natural conditions. No correlation values could be calculated between plant yield and seed yield in the field plantings since practically no seed was produced in the summer of 1935.

The fact that positive, linear or near-linear correlation ratio values were obtained between plant yields and root type (high yield and branched root system) in the *M. falcata* L. X *M. sativa* L. hybrids indicates that the genetic factors determining root type and plant yield capacity are not closely linked. Otherwise, the branched type of root system and low yield of the *M. falcata* L. parent would tend to occur together in the F_2 progeny. It also suggests, since a significant positive correlation was likewise obtained in a commercial variety, that on podsolic soils, at least, the well-branched type of root system, possibly through increasing feeding power, seems to make for greater productivity. Data not presented in this paper indicate that the branched type of root system may be associated with winter survival on these soils.

In an effort to determine how certain of the characters might be inherited in the next generation, selfed seed of two very different F_2 plants was grown in the greenhouse under conditions very similar to those experienced by the F_2 progeny. Number 9 was the highest yielding F_2 plant and had a well-branched type of root system, while No. 61 was one of the lowest yielding F_2 plants and had a distinct tap root. Figs. 2 and 3 demonstrate that these characters were transmitted to the progeny, and the expression of root type in such a limited quantity of soil leaves little doubt but that it is a heritable character. The behavior of F_3 progeny grown in the field, while producing less striking differences, tends to substantiate this conclusion.

FIG. 2. F_3 progenies of two widely different F_2 plants of *M. falcata* L. X Hairy Peruvian. No. 9 left; No. 61 right.

SUMMARY

One hundred F_2 progeny of a *M. falcata* L. X Hairy Peruvian hybrid were grown in the greenhouse in 1-gallon stone jars containing the equivalent of 4 kilograms of screened heavy Sassafras gravelly loam, low in available nutrients and having a pH of 5.6. Moisture content was maintained at a uniform and abnormally high level. Field progenies were grown in the above-described soil known to be unsuited to alfalfa production.

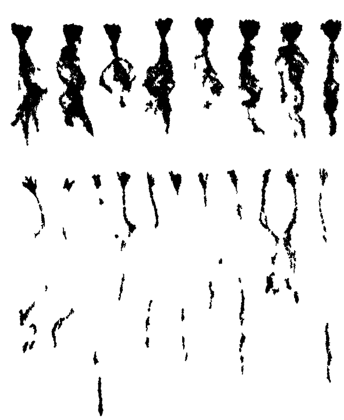

FIG. 3.—Representative root systems of the two F_3 progenies shown above. No. 9 above; No. 61 below.

Studies of the inheritance of several morphological characters and their relation to yield capacity led to the following conclusions:

Flower color is determined by three genetic factors, the exact mechanism of inheritance not being determined.

Stem length of 6-week-old plants, mature plant height, number of stems per plant, leaf index $\left(\frac{\text{width x 100}}{\text{length}}\right)$, leaf size (width x length), per cent of leaves, date of blooming, seed yield, and root type gave distribution curves closely approaching the normal, indicating that a

number of genetic factors control the expression of these characters. Correlation ratio values were calculated to determine the relation existing between each of three separate yield observations and the characters listed above. Significant correlation ratio values were obtained between plant yields and each of these characters except flower color.

Evidence of linkage between the genetic factors determining yield capacity and plant height, date of blooming, leaf index and leaf size was presented.

That root type is inherited was quite definitely proved and the results indicate that upon the heavier podsolic soils, at least, the well-branched type of root system makes for greater productivity.

Those characters and relations studied in field-grown F_2 progenies of this cross and of a *M. falcata* L. X Hardigan hybrid generally substantiate the above conclusions.

NOTE

IMPROVING THE PROTEIN CONTENT OF TIMOTHY (*PHLEUM PRATENSE*) BY APPLICATION OF SOLUBLE NITROGEN FERTILIZERS 10 TO 20 DAYS BEFORE HARVEST

THE improvement of protein content in harvested forage, particularly hay, is an important problem in the humid areas of the United States. Feeds of higher protein content than mature grasses normally contain are greatly desired in feeding dairy cattle, young stock of all types, and to a lesser extent for fattening livestock. At least two approaches may be made, *viz.*, either legumes may be found or developed which are well adapted to local soils and climatic conditions, or some means may be devised for raising the protein content of grasses and other nonlegumes.

Although the improvement of legumes by modern methods is receiving the earnest attention of plant breeders in many states, it is clear that several years must elapse before satisfactory species and strains of legumes will be available generally. At present, the grasses make up a major portion of the hay crop in humid regions. It has been known for many years that higher protein content of grasses could be achieved by early harvest of the crop. Unfortunately, such improved quality of feed necessitates reduced yields of total dry matter to the extent of 30 to 50%. In other words, the total protein per acre increases but little between the early heading and early seed stages of growth; consequently, the percentage of protein in the plant decreases steadily as the yield of dry matter increases

Efforts to improve the quality of grass hay by use of nitrogen fertilizers in winter or spring usually produce very substantial yield increases and increases in total protein per acre, but only minor increases in percentage of protein when the crop is harvested after the blooming period. Additional nitrogen is largely used by the plant for increased growth, and the protein percentage is maintained at or near the normal range for the species.

In 1930, a theory was devised which assumed that soluble nitrogen fertilizers applied 10 to 20 days prior to harvest of the crop would be absorbed by grass plants and converted into organic forms suitable for animal nutrition. Ten to 20 days, it was believed, would permit ample time for assimilation of soluble nitrogen, and prompt harvest would take advantage of the temporarily increased protein content before the plant could mobilize the nutrient for increased growth. Preliminary tests with nitrate of soda and sulfate of ammonia broadcast on timothy at the heading stage at the rate of 33 pounds of nitrogen per acre increased the total nitrogen content 1.05% to 2.1% when harvest occurred 12 days after treatment. The treated plants showed only 0.2% of nitrogen present in the inorganic form.

A similar experiment was performed in 1931 with two different strains of timothy grown on light sandy loam soil. Thirty-three pounds of nitrogen as sulfate of ammonia applied on June 13 increased the crude protein (N x 6.25) at harvest 21 days later from 6.1% to 9.4%. An equivalent amount of nitrate of soda increased the protein

to 10.5%. Approximately a 10% increase in total yield of dry matter occurred in the 21-day period after fertilization.

Lack of facilities delayed further investigations until 1934. New experiments were initiated at that time with the aid of Mr. Arthur Hawkins, research assistant in Agronomy. In a test with timothy sod transported from the field and grown in flats in the greenhouse, nitrate of soda applied at a 24-pound nitrogen rate at the beginning of heading raised the crude protein 10 days later to 11.0% in the dry crop, in contrast with 7.6% for untreated plats. Sulfate of ammonia in equivalent amount produced a protein content of 10.4%.

In 1935, a comprehensive field experiment with seven forms of nitrogen fertilizers used at rates varying from 20.5 to 41.0 pounds of nitrogen per acre, was conducted to determine the value of different materials and the efficiency in conversion of inorganic nitrogen to protein.

The crude protein content was increased 29.0% with nitrate of soda in 10 days and 46.0% in 20 days when compared with untreated check plats at the same dates of harvest. The efficiency in the conversion of inorganic nitrogen applied in fertilizer to crude protein of the plant varied from 32.0% for sulfate of ammonia (20 days after application) to 82.5% for calcium nitrate (10 days after application). Full details for the 1935 test have been presented in thesis form by Mr. Hawkins.[1]

The amount of soil moisture, rainfall, soil acidity, and nutrient supply, amount of plant growth and organic carbohydrate reserves, and the form and amount of nitrogen salt applied are factors which apparently control the efficiency of converting inorganic nitrogen to protein by means of timothy. Further investigation of these points was made in 1936 and will be repeated in 1937. It seems worthwhile to present these promising results at this time, however, since it may induce other workers to conduct similar experiments under different conditions of soils and climate and with different types of plants during the 1937 season. Recommendations are not being made to farmers pending the completion of the current tests. Since inorganic nitrogen is relatively inexpensive, since the materials are easily applied on a field scale, and since the efficiency of conversion to valuable protein is relatively high under suitable conditions, a careful study of this method of solving an important feed problem seems warranted.—HOWARD B. SPRAGUE, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

[1]HAWKINS, ARTHUR. The effect of deferred applications of nitrogenous fertilizers on the protein content of timothy hay. Thesis submitted in partial fulfillment of the requirements for the degree of master of science, Rutgers University, April, 1936.

PERCY EDGAR BROWN

DOCTOR Percy Edgar Brown, Secretary-Treasurer of the American Society of Agronomy since 1920, died at his home in Ames, Iowa, of coronary thrombosis on the morning of July 7. He is survived by his mother, Mrs. Jennett Brown, and a sister, Edna.

Dr. Brown was born in Woodbridge, New Jersey, in October 1885. He went to the Iowa State College in the fall of 1910 from Rutgers University where he had been associated with Dr. J. G. Lipman. At Iowa he first served as Assistant Professor of Soil Bacteriology, from 1910 to 1912. In 1913 he was made Professor of Soil Bacteriology. In 1931 he was named acting head of the Department, and from 1932 to the time of his death he served as head of the Department.

Dr. Brown was a Fellow of the Society and served as its President in 1932. But his chief service to the Society was as its Secretary and Treasurer. To this office he brought all of the efficiency, vigor, and untiring effort that marked all of his administrative activities, without reckoning the time and energy expended so long as the interests of the Society were served and the organization continued to prosper.

Few members of the Society outside of the executive officers knew that Dr. Brown even shouldered financial responsibilities on his own account during the dark months of the bank holiday and the peak of the depression in order that the JOURNAL and the other affairs of the Society might go forward with the least possible curtailment.

With the organization of the Soil Science Society of America last fall, Dr. Brown cheerfully assumed still heavier responsibilities and accepted additional demands upon his time in order that this latest development in the field of agronomy in America might get under way with a minimum of delay and inconvenience. The fact that the new soils society is functioning smoothly today is due very largely to his guidance in formulating policies and directing administrative detail.

The American Society of Agronomy has lost an officer to whom chief credit is due for the strong position in which the Society finds itself today with respect to membership and finances, and agronomic research has lost a keen and discerning student. And to all who had personal associations with Dr. Brown comes an overwhelming feeling of the loss of a staunch and sympathetic friend.

AGRONOMIC AFFAIRS

1937 PROGRAM OF SOIL SCIENCE SOCIETY

MEMBERS desiring to present papers before the 1937 meeting of the Soil Science Society should submit the title and a 200 to 500 word abstract of the paper to the Chairman of the appropriate Section as soon as possible, and in no case later than September 1. The manuscript should not exceed 5,000 words in length and should be submitted in form ready for publication at the meeting. The Section Chairmen for 1937 are as follows:

Section I. Soil Physics..........H. E. Middleton, Soil Conservation Service, Washington, D. C.

Section II. Soil Chemistry........S. F. Thornton, Purdue University, Lafayette, Indiana.

Section III. Soil Microbiology.....L. M. Turk, Michigan State College, East Lansing, Michigan.

Section IV. Soil Fertility.........W. H. Pierre, University of West Virginia, Morgantown, West Virginia.

Section V. Soil Morphology......L. C. Wheeting, Washington State College, Pullman, Washington.

Section VI. Soil Technology.......L. R. Schoenmann, University of Michigan, Ann Arbor, Michigan.

The PROCEEDINGS of the Soil Science Society for 1936, a cloth bound volume of 526 pages, is now available. Subscriptions (members \$4.50, nonmembers \$5.00) should be sent to the Secretary-Treasurer, Ames, Iowa.

MEETING OF SOUTHERN SECTION

THE Southern section of the Society will conduct a field tour in the heart of the Tennessee Valley area under the auspices of the University of Tennessee August 16 to 21. The tour will start at Knoxville on August 16 and will end at Muscle Shoals on August 21.

Agronomists outside the southern area are especially invited to participate in studying the work of the Tennessee Experiment Stations and observing the recent developments in the control of a great river system.

Information regarding hotel reservations and details of the itinerary may be obtained by addressing Professor O. W. Dynes of the Department of Agronomy, University of Tennessee, Knoxville, Tenn.

DR. LYON RETIRES

DOCTOR T. Lyttleton Lyon retired on July 1 as head of the Department of Agronomy at Cornell University, following 31 years of service on the Cornell faculty.

An authority on soils and a pioneer in agronomy, he achieved a nation-wide reputation for his work at Cornell. First in this country to develop a lysimeter to measure the percolation of rain through the soil, and co-author of a text book used in nearly all agricultural colleges in the United States, he leaves behind many other contributions in his field.

He planned Caldwell Hall, on the campus of the College of Agriculture, and was instrumental in having it named after Professor G. C. Caldwell, first teacher of soil chemistry at Cornell University; also the naming of Caldwell Field, where Cornell's lysimeters are located.

Primarily a research man, Dr. Lyon nevertheless was much interested in teaching and extension, and actively supervised these services in his department.

Dr. Lyon achieved recognition, also, in other lines, especially through research on maintaining soil nitrogen, the effects of plant growth on the accumulation of nitrates, nitrogen fixation, the volatilization of soil nitrogen, and other studies relating to the nitrogen cycle. His publications, appearing as bulletins of the Cornell University Agricultural Experiment Station, and in various scientific journals, present facts on many other phases of soil research.

For nearly thirty years he has maintained his earliest textbook on soil science, of which he was senior author in 1908, in such condition by constant revisions, that it has been used continuously at most of the agricultural colleges in the United States. The third revised edition of "The Nature and Properties of Soils", as the title now stands, by Dr. Lyon and Professor H. O. Buckman, appeared in April, 1937.

Dr. Lyon is a charter member of the Society and has long been active on committees, particularly within recent years when he has served as Chairman of the Editorial Advisory Committee. He is also Historian for the Society.

NEWS ITEMS

DR. RICHARD BRADFIELD, Professor of Soils, Ohio State University, has been named head of the Department of Agronomy at Cornell University following the retirement of Dr. T. L. Lyon.

DR. WALTER KUBIENA, professor of agricultural soil science in the Hochschule für Bodenkultur in Vienna, is spending six months in this country as guest professor in the Agronomy Department of the Iowa State College. Dr. Kubiena is giving a course of lectures on microscopic pedology and will conduct micropedological investigations on Iowa soils until his return to Austria in October.

DR. ARTHUR G. NORMAN, biochemist at the Rothamsted Experimental Station of England has been appointed professor of soil bacteriology in the Department of Agronomy of the Iowa State College. Dr. Norman is well known for his investigations on the biological decomposition of plant materials and will take up his work at the Iowa State College in September.

DR. WILL M. MYERS has resigned from his position in the Division of Agronomy and Plant Genetics, University of Minnesota, effective July 1, to become an Agent in the Division of Forage Crops and Diseases in connection with a new pasture research laboratory at State College, Pennsylvania.

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BASICITY OF SOME PHOSPHATES AS RELATED TO NITRIFICATION[1]

G. S. FRAPS AND A. J. STERGES[2]

IT has been known for many years that the use of ammonium sulfate in the course of a number of years will make some soils acid (2, 15).[3] Slight acidity is detrimental to some crops, while favorable to others, but too much acidity is not favorable to the growth of most cultivated plants Many mixed fertilizers tend to increase soil acidity. The question of acid-forming fertilizers has become important in recent years, especially in the eastern part of the country where fertilizers have been used over a long period of time. It seems possible to manufacture non-acid-forming fertilizers by proper selection of ingredients, as well as by the addition of dolomite.

A method (11) has recently been proposed for estimating the equivalent acidity or basicity of fertilizers, or the effect of the fertilizer upon the permanent acidity of the soil. This method is based upon the assumption, insofar as permanent acidity is concerned, that monocalcium phosphate is neutral, that dicalcium phosphate contains one basic calcium ion, that both calcium fluophosphate and tricalcium phosphate are neutral, and that one-half of the nitrogen in fertilizers is acid-forming. Sulfates, chlorides, and part of the phosphates combined with ammonia are considered to be acid-forming. This method has been adopted as tentative by the Association of Official Agricultural Chemists (8) to distinguish between acid-forming and non-acid-forming fertilizers.

The data available as to the exact quantitative effect of different fertilizer materials upon the soil is not, at present, sufficient to form a satisfactory basis for a method to measure exactly the quantitative effect of fertilizers and fertilizer materials. There are some differences of opinion regarding the quantitative effect of various constituents of fertilizers upon soil acidity. The quantitative measurements are limited in number and subject to large errors. There is evidence from field tests that superphosphate has little effect upon soil acidity and that

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[3]Figures in parenthesis refer to "Literature Cited", p. 621.

rock phosphate does not decrease soil acidity. There is a little evidence that dicalcium phosphate is basic (3, 10). The effect of fertilizers on soil acidity will undoubtedly depend to some extent upon the chemical composition of the soil, its physical character, the climatic conditions, including especially the temperature and amount and distribution of rainfall, the crop grown, etc.

Work in this laboratory (7) has shown that many soils which naturally have a low or medium nitrifying power for ammonium sulfate can be caused to nitrify well by additions of calcium carbonate. That the principal effect of calcium carbonate in such cases is to neutralize the acids produced in nitrification is generally recognized (1, 5, 14). It was considered desirable to ascertain whether dicalcium phosphate or rock phosphate would have a favorable effect upon nitrification in soils of this kind, and whether or not, in that respect, these fertilizer constituents were basic. This was the object of the work here presented.

METHOD OF PROCEDURE

Soils were selected which, when untreated, were low or moderate in nitrifying capacity but nitrified well when supplied with calcium carbonate. Three samples of pure finely-divided dicalcium phosphate, four of ground rock phosphate, one of soft phosphate with colloidal clay, and one each of dolomite and pure precipitated magnesium carbonate were used for the purpose of comparing their effect upon nitrification with that produced by additions of pure precipitated calcium carbonate. Since the acid-base balance of the dicalcium phosphate was a little over 500 as measured by Pierre's method, while that of the calcium carbonate was nearly 2,000, 8 grams of dicalcium phosphate were used to compare with 2 grams of calcium carbonate in two series of tests. In another series, one-fourth as much dicalcium phosphate was used. The dolomite was not as finely divided as the calcium carbonate.

Two series of nitrification tests were made by the procedure previously described (7) in which 200 grams of soil were mixed with the material to be tested, 0.1 gram nitrogen in the form of ammonium sulfate and water equal to one-half of its water capacity were added, and the mixture incubated for 28 days at 35° C, the loss of water being restored from time to time. The period of 28 days is sufficient to nitrify all the nitrogen of the ammonium sulfate when the soil has a high nitrifying capacity. At the end of that period, nitrates, nitrites, and pH values were determined (6). In a third series of tests (Table 3), 100 grams of soil and 0.05 gram of nitrogen was used, with 1 gram of dicalcium phosphate instead of 8 grams to 200 grams of soil as in the previous series. The pH was estimated by the quinhydrone method.

EFFECT ON NITRIFICATION

Table 1 shows the net quantity of nitrite and nitrate nitrogen formed from the ammonium sulfate in one series of 15 tests with 10 soils. The quantities of nitrite and nitrate nitrogen in each sample with ammonium sulfate alone were deducted from the total quantities produced from the same soil with ammonium sulfate and the substance being tested. Table 2 shows the nitrification in 10 additional soils and Table 3 for dicalcium phosphate only on 12 soils.

TABLE 1.—*Ammonium nitrogen, in parts per million, nitrified due to additions.*

Soil No.	Soil type and depth in inches	Calcium carbonate, 2 grams	Calcium carbonate, 1 gram	Calcium carbonate, 0.5 gram	Rock phosphate No. 33424, 8 grams	Soft phosphate No. 40897, 8 grams	Dicalcium phosphate No. 36385, 5 grams	Dicalcium phosphate No. 8260, 8 grams	Calcium carbonate, 2 grams	Dolomite No. 40860, 2 grams	Dicalcium phosphate No. 23139, 8 grams	Check
37286	Lazare clay loam, 0–7	361	374	244	-6	9	-36	-59	324	311	—	176
37287	Lazare clay loam, 7–19	298	342	282	-5	12	-26	-36	384	242	—	58
37287	Lazare clay loam, ——	279	224	167	-4	0	-29	-33	291	200	—	50
37294	Quanah fine sand, 19–31	357	385	221	20	11	-17	-2	367	289	—	31
37295	Quanah fine sand, 0–7	236	248	145	0	-5	-60	-41	251	155	—	225
37296	Quanah fine sand, 7–19	370	351	262	-20	-10	-60	-72	387	350	—	110
39681	Duval fine sandy loam, 0–12	297	331	188	4	30	12	-4	328	805	22	86
39682	Duval fine sandy loam, 12–30	260	264	207	10	24	-4	-22	329	190	5	52
39682	Duval fine sandy loam, 12–30	349	296	220	-4	31	-24	-39	418	254	—	57
39699	Webb fine sandy loam, 15–42	326	233	125	-1	7	-3	-2	405	250	5	12
39699	Webb fine sandy loam, 15–42	236	213	107	1	11	-1	3	371	180	—	10
39881	Wilson clay loam, 0–7	464	323	115	-1	-1	-20	-3	501	238	—	37
39881	Wilson clay loam, 0–7	481	349	149	-7	-5	-26	-4	515	329	—	41
39884	Wilson very fine sandy, loam, 10–19	265	329	218	-7	18	-10	-21	430	178	—	32
39884	Wilson very fine sandy loam, 10–19	359	318	210	23	25	10	-7	472	222	—	15
Average		329	305	191	0.2	10	-20	-23	385	246	11	—

TABLE 2.—*Ammonium nitrogen, parts per million, nitrified due to additions.*

Soil No.	Soil type and depth in inches	Calcium carbonate, 2 grams	Calcium carbonate, 1 grams	Calcium carbonate, 0.5 gram	Ground rock phosphate No. 41392, 8 grams	Ground Tennessee rock phosphate No. 41410, 8 grams	Rock phosphate No. 41403, 8 grams	Rock phosphate No. 33403, 8 grams	Dicalcium phosphate No. 8260, 8 grams	Dicalcium phosphate No. 36385, 2 grams	Dolomite No. 40860, 2 grams	Magnesium carbonate, 2 grams	Check
37292	Quanah fine sand, 0–7	338	304	156	–8	0	0	–16	0	–80	94	143	156
37294	Quanah fine sand, 19–31	435	425	378	6	–8	13	26	6	–22	296	362	50
37646	Bowie fine sandy loam, 0–7	280	295	184	8	12	19	21	20	–2	200	109	15
37648	Douglasville fine sandy loam, 0–7	360	316	206	3	1	4	5	5	–2	168	117	12
37650	Nacogdoches fine sandy loam, 0–7	300	300	179	24	5	13	20	25	–6	283	218	40
37651	Nacogdoches fine sandy loam, 7–19	340	289	136	6	0	6	5	19	3	317	360	8
37652	Ruston fine sandy loam, 0–7	285	305	218	2	1	10	12	–5	–15	246	106	21
39883	Wilson very fine sandy loam, 0–7	395	380	77	10	–10	0	10	0	–55	365	387	110
41179	Wilson clay loam, 7–19	108	88	58	–25	–50	–39	–2	–200	—	138	64	312
41187	Denton clay, 7–19	255	230	46	–33	–52	–27	–27	–150	—	167	242	320
Average		310	293	164	–0.7	–10	–0.1	5	–28	–22	227	211	—

It is evident from the 70 tests with rock phosphate and soft phosphate that they had practically no effect upon nitrification, the average effect of 8 grams per culture being a minus quantity. Insofar as nitrification is concerned, these samples of rock phosphate are neutral.

The dicalcium phosphate in 65 tests on 32 soils had no favorable effect upon nitrification when 8 grams in 200 grams of soil were compared with 0.5 gram of calcium carbonate (Tables 1 and 2), or when the quantity was reduced to 1 gram in 100 grams of soil (Table 3). Insofar as these nitrification experiments are concerned, dicalcium phosphate is neutral.

TABLE 3.—*Ammonia nitrogen nitrified and acidity (pH) in soils without and with dicalcium phosphate.*

Soil No.	Soil type and depth in inches	Parts per million of nitric nitrogen		Acidity (pH)	
		Without	With	Without	With
35112	Miles fine sandy loam, shallow phase, 0-7	41	11	6.6	6.7
35113	Miles fine sandy loam, shallow phase, 7-24	51	4	6.4	6.7
35168	Norfolk fine sand, 7-36	37	4	6.4	6.6
35169	Norfolk fine sand, 0-7	58	8	6.4	6.7
35172	Susquehanna fine sandy loam, 0-7	47	7	6.4	6.6
36369	Amarillo fine sandy loam, 0-7	64	8	6.4	6.6
36487	Refugio fine sand, 0-7	69	6	6.1	6.6
36488	Refugio fine sand, 7-10	54	19	6.3	6.4
37652	Ruston fine sandy loam, 0-7	50	10	6.1	6.5
39686	Pryor clay, 0-30	128	78	7.3	7.3
43387	Leaf fine sandy loam, 3-7	5	4	6.4	6.4
43402	Crockett very fine sandy loam, 7-13	0	2	4.2	5.1
Average		50	13	6.2	6.5

The dolomite was not as effective as calcium carbonate. An average of the results in both tables shows that the 2 grams of dolomite used produced a little more nitrification than 0.5 gram of calcium carbonate. This may be partly due to the dolomite being less finely divided than the calcium carbonate. The increase in nitrification caused by magnesium carbonate (Table 2) averaged nearly the same as the dolomite. The effect of two samples of calcium carbonate varied somewhat with the different soils. The results with one sample were on an average appreciably higher than with the other.

Considerable quantities of nitrite nitrogen were found in many of these soils to which calcium carbonate, dolomite, or magnesium carbonate had been added.

EFFECT ON ACIDITY (PH)

The pH of the soils after nitrification is given in Tables 3, 4, and 5. Calcium carbonate, dolomite, and magnesium carbonate made the soils slightly more alkaline, dicalcium phosphate made some slightly more acid and others slightly more alkaline, while the rock phosphate on an average had practically no effect upon the acidity (pH).

TABLE 4.—*Acidity (pH) due to additions.*

Soil No.	Check	Calcium carbonate, 2 grams	Calcium carbonate, 1 gram	Calcium carbonate, 0.5 gram	Rock phosphate, 8 grams	Soft phosphate with colloidal clay, 8 grams	Dicalcium phosphate, 5 grams	Dicalcium phosphate, 8 grams	Calcium carbonate, 2 grams	Dolomite, 2 grams	Dicalcium phosphate, 8 grams
37286	5.7	6.7	7.2	6.9	6.6	6.5	6.2	6.1	6.7	6.6	—
37287	6.6	7.0	7.2	7.1	7.2	6.9	6.9	6.5	7.1	7.0	—
37287	6.9	7.5	7.5	7.5	7.0	7.1	6.9	6.5	6.9	7.0	—
37294	6.7	7.3	7.4	7.3	6.6	6.7	6.4	6.2	7.1	7.0	—
37295	6.4	7.3	7.3	7.2	6.2	6.3	6.1	5.8	6.7	6.6	—
37296	6.3	6.9	7.1	6.9	6.5	6.6	6.5	6.4	7.1	7.1	—
39681	7.0	7.4	7.5	7.5	7.1	6.7	6.5	6.1	6.7	7.3	6.2
39682	6.5	7.5	7.3	7.3	6.9	6.9	6.5	6.3	7.2	7.3	6.4
39682	6.4	7.5	7.4	7.3	6.9	6.5	6.5	6.3	7.0	7.1	—
39699	7.2	7.4	7.5	7.3	7.0	6.7	6.6	6.3	6.9	7.1	6.3
39699	6.4	7.3	7.4	7.1	6.6	6.3	6.1	5.9	7.0	7.0	—
39881	6.4	7.1	7.2	6.7	6.2	6.0	5.9	5.8	7.1	7.0	—
39881	6.6	7.3	6.9	6.7	6.2	6.2	6.1	5.9	7.0	6.9	—
39884	6.4	7.3	7.4	7.2	6.6	6.6	6.4	6.2	7.0	7.1	—
39884	6.7	7.3	7.4	7.2	6.9	6.8	6.6	6.2	6.8	7.0	—
Average	6.5	7.3	7.3	7.1	6.7	6.6	6.4	6.2	6.9	7.0	6.3

TABLE 5.—*Changes in acidity (pH) due to additions.*

Soil No.	Check	Calcium carbonate, 2 grams	Calcium carbonate, 1 gram	Calcium carbonate, 0.5 gram	Ground rock phosphate, 8 grams	Ground Tennessee rock phosphate, 8 grams	Rock phosphate, 8 grams	Rock phosphate, 8 grams	Dicalcium phosphate, 8 grams	Dicalcium phosphate, 8 grams	Dolomite, 2 grams	Magnesium carbonate, 2 grams
37292	5.6	7.3	7.6	7.0	5.7	5.4	5.4	5.4	5.2	5.5	6.7	8.4
37294	6.1	7.4	7.3	6.8	5.8	5.9	5.7	5.6	5.6	5.7	6.8	8.1
37646	5.7	7.3	7.4	7.0	5.7	5.5	5.5	5.6	5.7	5.7	6.6	8.4
37648	6.2	7.2	7.3	6.9	5.9	5.8	5.8	5.8	5.7	5.7	6.3	8.3
37650	5.7	7.3	7.4	6.8	5.5	5.6	5.6	5.8	5.7	5.8	6.7	8.3
37651	5.9	7.3	7.1	6.5	5.8	5.6	5.7	5.8	5.8	5.9	6.7	7.6
37652	5.9	7.4	7.4	6.9	6.0	5.9	5.7	5.9	5.9	5.9	6.5	8.5
39883	4.5	7.2	7.2	6.6	4.7	4.6	4.6	6.3	5.1	5.1	6.4	7.9
41179	7.1	7.8	7.8	7.7	7.1	7.1	7.1	7.0	6.3	7.2	7.5	8.1
41187	6.6	7.7	7.6	7.2	6.4	6.3	6.6	6.3	6.0	6.5	7.0	7.5
Average	5.9	7.4	7.4	6.9	5.9	5.8	5.8	6.0	5.7	5.9	6.7	8.1

With 10 soils in Table 3, soils Nos. 37286 and 37287 in Table 4, and Soil No. 39883 in Table 5, the pH values of the cultures which received dicalcium phosphate were higher than those of the corresponding check cultures so that apparently the dicalcium phosphate was basic in these soils. In the other 19 soils, the dicalcium phosphate either had practically no effect on the pH or made the soils slightly more acid.

Pierre (10), in tumbler experiments, found from the pH that dicalcium phosphate in 6 weeks acted as basic in a soil of medium acidity and in one highly acid, but had little or no effect on a slightly acid soil. When the pH alone is considered, dicalcium phosphate may apparently be basic in some soils and neutral or slightly acid in others. It is possible that longer period of contact might show greater basicity for the dicalcium phosphate. However, according to the results of Pierre (10), three samples which received dicalcium phosphate were more acid after 1 year than after 6 weeks, two were slightly less acid, and only one appreciably less acid (0.24 pH). After 1½ years, two were more acid than at the end of 6 weeks and two were slightly less acid. Some of these results were probably within the limit of error Thus, there may or may not be a greater basic action of the dicalcium phosphate after a longer period of contact with the soil.

Since there are errors both in the sampling and in the estimation of pH, we do not attach importance to small differences. We are primarily concerned with the results of the nitrification work.

DISCUSSION

The function of calcium carbonate, magnesium carbonate, or dolomite in causing nitrification to occur in certain soils is probably due in large part to their power to neutralize the acids present or produced. Since calcium is present in calcium carbonate, dicalcium carbonate, and phosphate rock, the differences are chiefly in the carbonate and phosphate portion of the compounds. The ineffectiveness of rock phosphate may be due to the fact that it is only slightly soluble under the conditions of nitrification. Dicalcium phosphate may be too stable to neutralize the acids produced during nitrification.

In either case dicalcium phosphate, soft phosphate, and rock phosphate are ineffective in promoting nitrification at the same time that calcium carbonate, magnesium carbonate, and dolomite are highly effective. It does not follow, however, that dicalcium phosphate would be ineffective in aiding to prevent some soils from becoming acid during a long period of time, since other reactions in addition to neutralization of acidity may occur.

As pointed out by Conner (3) and Pierre (10), the phosphates might combine with iron and aluminum compounds in some soils, leaving the calcium free to replace hydrogen ions in the soil complex. Some soils may not contain sufficient iron and aluminum compounds for the purpose of this reaction. Prince and Toth (12) show that superphosphates may slightly decrease the pH of the soil and at the same time increase the exchangeable hydrogen and the total exchange capacity. The ineffectiveness of dicalcium phosphate with respect to nitrification

increases the necessity of having more evidence that it has an appreciable effect in reducing soil acidity, or in reducing the acidity due to acid-forming constituents of a mixed fertilizer.

SUMMARY

In slightly acid soils which required additions of calcium carbonate in order to nitrify well, neither dicalcium phosphate in 32 soils nor rock phosphate in 20 soils had an appreciable effect on the nitrification of ammonium sulfate. Additions of magnesium carbonate and dolomite increased nitrification but not as much as did the addition of calcium carbonate. So far as nitrification is concerned, dicalcium phosphate and rock phosphate are neutral and not basic. The effect of dicalcium phosphate on the acidity (pH) was not always the same, decreasing the acidity of some soils and either increasing the acidity in others or having no appreciable effect.

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BREEDING WINTER OATS RESISTANT TO CROWN RUST, SMUT, AND COLD[1]

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THE varieties of winter common oats belonging to *Avena sativa* L., such as Winter Turf, Lee, and Culberson, that are grown in the northern part of the winter-oat belt of the South and in western Oregon and Washington, are, as a group, very susceptible to smuts and rusts. In most sections where these varieties are grown smut is usually prevalent and crown rust frequently damages the crop. As a rule, stem rust has been less prevalent and, therefore, has not been a serious limiting factor in the production of winter common oats. The objective of the investigations here reported has been to develop strains of these hardier types that are resistant to smut and crown rust. In addition to disease resistance interesting data have been obtained on the use of artificial freezing as a means of isolating cold-resistant strains These investigations have been conducted as one phase of the general breeding program of the project on oat improvement of the Division of Cereal Crops and Diseases of the U. S. Dept. of Agriculture.

REVIEW OF LITERATURE

Stanton *et al.* (6)[3] and Murphy, Stanton, and Coffman (4) have reported the development of strains of oats with a combination of resistance to crown and stem rusts, and the smuts of oats. These were effected by crossing the comparatively newly introduced Victoria and Bond varieties that are highly resistant to crown rust and smut on Richland and Iogold, leading stem-rust resistant economic varieties of the Corn Belt.

McClelland and Kapp (1, pages 14–15), in the winter of 1934–35, subjected both greenhouse and field-grown seedlings of winter oats to artificial freezing. The oats were sown in or transplanted to flats 10 by 16 inches and 4 inches deep. Because of the shallow seedbed, heat was withdrawn from all surfaces, even beneath. This procedure is not possible under field conditions. Custis (C. I. 2041)[4] winter oats, sown on September 27 and exposed on November 27 and following dates, withstood exposures as low as 12° F for 16 hours. All plants, however, were badly damaged at 20° or lower when exposed as long as 20 hours. At the latter exposure there was complete freezing of the soil and roots. Three-tiller plants were more hardy than 2-tiller or 1-tiller plants. In a second series of experiments with younger seedlings, it was observed that seedlings 9 to 14 days old could not withstand temperatures of 22° F for 18 hours or more. Seedlings that had been fertilized showed greater resistance to freezing.

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[1]Results of cooperative investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa and Idaho Agricultural Experiment Stations. Journal Paper No. J-436 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 73. Received for publication March 15, 1937.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 637.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly the Office of Cereal Investigations, U. S. Dept. of Agriculture.

MATERIALS AND METHODS

HYBRIDS AND PROCEDURE

The hybrids, Lee x Victoria (X S1110) and Hairy Culberson x Victoria (X S1113), were made in the greenhouse at the Arlington Experiment Farm, Arlington, Va., in March 1931. The F_1 plants were grown at the Aberdeen Substation, Aberdeen, Idaho, in the summer of 1931. Seed from F_1 plants was sown at Aberdeen in the spring of 1932, and all F_2 seedlings showing a prostrate habit of growth were marked. Forty-seven out of a total of approximately 600 seedlings were prostrate. Seed from these 47 plants was sent to Ames, Iowa, for testing the F_3 generation for resistance to crown rust and cold in greenhouse and laboratory during the winter of 1934–35. Seed from the F_3 plants that survived freezing and showed resistance to crown rust in these initial tests was sown at Aberdeen in the spring of 1935.

Several smut-infected plants appeared in the F_4 populations of the cross and were immediately discarded. Many other plants showing undesirable grain characters likewise were discarded. From the remaining plants F_5 populations were grown simultaneously in greenhouses at the Arlington farm and at Ames, Iowa, in the winter of 1935–36. These populations were subjected to tests for smut and crown rust at both places and to freezing only at Ames. Seed from certain F_4 families also was sown in the winter-oat nursery at the Arlington farm in the fall of 1935. In 1936, F_6 populations were grown at Aberdeen, Idaho, from the lines that were promising at both Ames and the Arlington farm. The resulting progenies that showed desirable grain characters and were uniform in heading and ripening were harvested *en masse* for sowing in the field in winter oat nurseries in the fall of 1936. In other rows plants were harvested individually for further greenhouse and laboratory tests of resistance to crown rust, smut, and cold in the winter of 1936–37. Seed of certain individual plants also was sown in plant rows in nurseries at the Arlington farm and at the Piedmont Branch Station, Statesville, North Carolina, in the fall of 1936.

INOCULATION FOR CROWN RUST AND SMUT

The inoculations for both smut and crown rust were made in the usual manner, as described by the writers in previous publications (2, 6, 4). Smut spores collected from Lee or from Lee oat hybrids were used primarily for inoculation, representing a physiologic race similar or identical to Reed's *Ustilago avenae*—Missouri. All seed was hulled before inoculation. The highly virulent physiologic race 1, so widely prevalent in the South, was used for the inoculations of crown rust. Reaction to crown rust under greenhouse conditions was recorded, the host-reaction types 0 to 4 being used. Under field conditions host-reaction types 1 to 10 were used and percentage of infection also was recorded. This procedure is fully described by Murphy (2).

FREEZING CHAMBERS AND METHODS

Seedling plants in the rosette stage with from three to seven tillers were used for all freezing tests. The selections were sown in 4-inch pots with a sufficient number of seeds to allow thinning to five plants per pot. Greenhouse temperatures were automatically controlled at 60° to 65° F until the rosette stage had fully developed, then the plants were hardened for 10 to 14 days in a greenhouse room automatically maintained at 38° to 42°. Automatic temperature controls used in

the greenhouse allowed for control of heat and ventilation only and did not include artificial cooling. For this reason all experiments were conducted during the winter when the outside temperature ordinarily would allow a constant greenhouse temperature of 42° or lower. Whenever necessary the hardening plants were removed to a refrigerator room maintained constantly at 40° F. Plants were frozen by subjecting them to 20° F for a period of 24 or 48 hours. The pots were placed in the freezing chambers in groups of not more than 50 so that all of them might be kept at floor level and be uniformly exposed. All plants were watered uniformly approximately 4 hours before being placed in the freezing chambers.

Following exposure to freezing temperatures the plants were returned to the 38° to 42° room for a period of two weeks. The surviving plants were then removed to the 60° to 65° room and grown to maturity for smut notes and seed. Estimates (Table 1) of the condition of the plants 5 and 10 days after freezing were made following the criteria described by Quisenberry (5).

TABLE 1.—*Criteria for evaluating plant condition 5 and 10 days after exposure to freezing temperatures* *

Description	Visible criteria	Assigned numerical value
Dead ..	No sign of life	0
Very weak .. .	Showing only small amounts of living tissue	4
Weak .	Leaves more than half killed	8
Heavy injury..	Leaves about half killed .	12
Light injury	Tips of leaves killed	16
No injury .	No sign of killing	20

*After Quisenberry (5)

EXPERIMENTAL DATA

F_3 POPULATION

The reaction of the F_3 plants to crown rust (*Puccinia coronata*) and cold (artificially developed) is shown in Table 2. The reactions recorded for crown rust represent the ranges observed for 10 seedling

TABLE 2.—*Reaction to crown rust (Puccinia coronata) physiologic race 1 and freezing of progenies of F_2 prostrate plants from the Lee × Victoria and Hairy Culberson × Victoria oat crosses grown in F_3 at Ames, Iowa, during the winter of 1934-35.*

Aberdeen F_2 prostrate plant No.	Seedling reaction to race 1 of crown rust*	Average 5- and 10-day condition indices			
		Freezing experiment number			Total
		1†	2†	3‡	
		Lee × Victoria			
1	0-1	20	20	21	52
2	2	18	12	8	38
3	3-4.	18	12	4	34
4	4	20	18	10	48
5	Seg.	18	10	6	34
6	Do	18	16	5	39
7	0-1	18	10	0	28
8	3-4	20	10	0	30
9	3-4	20	18	10	48

TABLE 2.—*Concluded.*

Aberdeen F_3 prostrate plant No.	Seedling reaction to race 1 of crown rust*	Average 5- and 10-day condition indices			
		Freezing experiment number			Total
		1†	2†	3‡	
		Lee × Victoria			
10	0–2	18	12	0	30
11	Seg.	20	20	13	53
12	0	16	14	0	30
13	0–2	16	14	0	30
14	3–4	14	12	2	28
15	Seg.	16	0	0	16
16	1–2	16	4	0	20
17	1–2	18	6	0	24
18	Seg.	16	6	0	22
19	Do	18	10	0	28
20	1–2	18	12	0	30
21	3–4	20	18	12	50
22	Seg.	18	14	10	42
23	Do	16	12	6	34
24	Do	16	12	4	32
25	Do	12	2	0	14
26	3 4	20	18	10	48
27	3–4	18	14	2	34
28	Seg.	16	12	2	30
29	Do	10	5	0	15
30	0–1	20	18	14	52
31	Seg.	18	18	8	44
32	0–1	16	18	10	44
33	Seg.	19	16	12	47
34	0–2	18	16	10	44
35	Seg.	16	12	1	29
36	3–4	18	14	10	42
37	Seg.	12	10	0	22
38	0–1	16	12	8	36
39	0–1	20	19	12	51
40	Seg.	18	16	6	40
		Hairy Culberson × Victoria			
41	Do	20	18	10	48
42	3–4	18	16	2	36
43	0–1	18	18	10	46
44	0–1	20	20	10	50
45	Seg.	16	12	1	29
46	Do	20	16	8	44
47	Do	18	12	8	38
		Lee Parent (C I. 2042)			
—	4	20	16	8	44
		Victoria Parent (C. I. 2401)			
—	0–1	16	10	0	26
		Hairy Culberson Parent (C. I. 2505)			
—	4	20	20	10	50

*Seedling reaction recorded using 0 to 4 scale with 0 indicating nearly immune reaction and 4 a completely susceptible reaction. Seg. = segregating for resistant and susceptible plants.
†Exposure of 24 hours at 20° F.
‡Exposure of 48 hours at 20° F.

plants of each selection inoculated with physiologic race 1. Three separate freezing tests were made by exposing the plants 24 hours at 20° F in November and February and 48 hours at 20° in March. The condition value recorded for each selection in each experiment represents the average of estimates of the five plants 5 and 10 days after freezing.

Of the 47 F_3 progenies tested 16 appeared homozygous for resistance to crown rust, 21 showed segregation for resistant and susceptible plants, and 10 were homozygous susceptible. This distribution suggests a 1:2:1 ratio in the F_2. Selection of prostrate F_2 plants might have affected the distribution.

There was an evident tendency for transgressive segregation with respect to reaction to cold in the cross of Lee × Victoria. Certain progenies appeared much more susceptible than Victoria, while a few appeared to have considerably more resistance than the winterhardy parent variety. This tendency was not expressed in the Hairy Culberson × Victoria cross, possibly because only seven progenies of this combination were studied.

Seventeen of the 47 F_3 progenies were selected for further study in F_4 Only five of these were homozygous for resistance to crown rust and were also apparently highly resistant to cold. Progenies appearing homozygous either for undesirable grain characters or susceptibility to crown rust, or those apparently below the Lee variety in cold resistance, were not continued into F_4

F_4 POPULATION

The reaction of the F_4 plants to smut inoculation in the field at Aberdeen, Idaho, in 1935 is shown in Table 3 Progeny rows of these same families also were grown at Ames, Iowa, and subjected to an artificially developed epiphytotic of crown rust during the summer of 1935. The reaction of these lines to crown rust also is recorded in Table 3.

According to the data given in Table 3, smut occurred in only two families of the Lee × Victoria cross and in none of the Hairy Culberson × Victoria. With the exception of the one family from the cross of Hairy Culberson × Victoria, all crown-rust readings at Ames were satisfactory. The reaction of the Lee and Hairy Culberson parents to both smut and crown rust indicates that the methods of inoculation used for both diseases were quite satisfactory.

Of a total of 548 hulled hybrid seed sown at Aberdeen, in 1935, 384, or 70.1%, produced plants Even though the seed for this experiment was not sown until about May 1, all plants developed fully and matured seed. There was little indication of segregation as to winter type plants. Apparently the temperatures were sufficiently low to permit the natural heading of winter habit plants

Only those plants coming from smut-free populations at Aberdeen, with fair to good grain characters, were conserved for further testing

TABLE 3.—*Reaction to smut of smut-crown-rust- and cold-resistant selections from the Lee × Victoria and Hairy Culberson × Victoria oat crosses grown in F_4 at the Aberdeen Substation, Aberdeen, Idaho, 1935.*

F_3 plant No.	Number of seed sown	Number of plants: Matured (total)	Number of plants: Smutted	Field reaction to crown rust at Ames, Iowa, 1935 (adult)*
		Lee × Victoria		
1	80	63	0	3-30†
2	20	14	1	4-40
5	40	27	0	3-30
6	40	31	0	Seg.
11	20	12	0	Do
22	40	25	0	Do
30	20	13	0	4-30
31	40	23	0	Seg.
32	20	13	1	2-30
33	10	6	0	Seg
34	20	17	0	Do
38	40	31	0	Do
39	12	4	0	2-20
40	6	6	0	2-20
		Hairy Culberson × Victoria		
41	40	33	0	10-80
43	80	53	0	2-20
44	20	13	0	2-30
		Lee Parent (C. I. 2042)		
-	20	15	11	10-90
		Victoria Parent (C. I. 2401)		
-	20	16	0	2-20
		Hairy Culberson Parent (C. I. 2505)		
—	20	16	4	10-90

*Race 1 was used for artificially inoculating plants, but other races were present as a result of natural infection.

†Reaction to crown rust under field conditions was recorded as follows: 3-30 = an infection type 3 (on a 1 to 10 scale with 1 indicating an apparently immune reaction and 10 indicating a completely susceptible reaction) of 30% severity, seg = segregating for resistant and susceptible plants.

F_5 POPULATION

As already described, smut-inoculated seed from 119 plants from 13 F_4 families were sown in identical cultures at Ames and at the Arlington farm, respectively, in the fall of 1935. The reaction of these progenies to smut, crown rust, and freezing is shown in Table 4. Owing to the lack of satisfactory freezing chambers, no tests for cold resistance were made at the Arlington farm. However, a 5-foot plant row from each of a number of the 119 F_4 plants was sown from surplus seed in the winter oat nursery at the Arlington farm in the fall of 1935 with the result that about 95% were destroyed by the severe cold winter that followed. All space-planted, winterhardy varieties and strains at the same station likewise were nearly 100% destroyed.

The extensive data shown in Table 4 will be discussed on the basis of resistance to (a) cold, (b) crown rust, and (c) smut.

Reaction of selections to artificial freezing.—Although a uniform exposure of 24 hours at 20° F was used for the five different freezing

TABLE 4.—*Reaction of selections from Lee × Victoria and Hairy Culberson × Victoria oat crosses grown in the greenhouse at Ames, Iowa, and the Arlington Experiment Farm, Arlington, Va., to crown rust and smut infection at both stations, and to freezing at Ames, 1935–36.*

Varieties crossed and progeny No.	Av. 5- and 10-day condition indices (Ames)†						Reaction to physiologic race 1 of crown rust at		Reaction to smut at				
	Freezing experiment No.					Total	Ames (seedling)	Arlington (adult)	Ames		Arlington		Total smutted, %
									Plants		Plants		
	1	2	3	4	5				Grown, number	Smutted, number	Grown, number	Smutted, number	
Lee parent	16	7	15	14	18	70	4	3–4	5	5	7	7	100
Victoria parent	6	0	7	8	12	33	1	0–1	2	0	12	0	0
Hairy Culberson parent	19	14	20	17	20	90	4	3	10	8	10	10	90
Lee × Victoria													
P-1-1	17	6	14	10	15	62	0	0	3	0	3	0	0
-2	18	13	20	16	19	86	1	0	10	8	1	1	82
-3	17	12	20	13	18	80	1	2	5	3	4	4	78
-4	17	12	20	13	18	80	1	2	10	2	5	0	13
-5	16	13	19	16	10	74	1	1	5	1	3	2	38
-6	19	14	20	16	20	89	0	1	5	2	4	1	33
-7*	19	13	20	18	20	90	0	0	5	0	5	0	0
-8	15	14	18	15	17	79	1	0	5	2	4	4	67
-9	16	14	18	17	18	83	0	1	5	1	4	1	22
-10*	19	15	20	20	20	94	0	1	5	0	4	0	0
-11	20	18	20	19	20	97	1	0	5	0	5	1	10
-12	20	18	20	19	20	97	1	1	10	1	5	1	13
-13*	19	14	20	18	19	90	1	0	5	0	3	0	0
-14*	18	15	20	16	14	83	1	2	5	0	4	0	0
-15	20	18	20	20	20	98	1	2	10	2	3	1	23
-16	20	18	20	20	20	98	1	1	10	2	4	1	21
-17	20	18	20	20	20	98	1	2	10	1	3	0	8
-18*	18	15	18	20	20	91	1	2	5	0	4	0	0
-19*	19	17	20	19	20	95	1	1	10	0	3	0	0
-20*	19	15	20	20	20	94	1	2	5	0	4	0	0

P–2–1	17	13	15	10	12	67	2	2	4	0	2	1	17
–2	9	10	8	5	6	38	1	3	5	0	2	0	0
–3	13	12	12	11	10	58	1–2	2	—	—	4	1	25
P–5–1*	14	14	13	11	8	60	1–2	2	—	—	4	0	0
–2*	18	12	15	14	16	75	4	2	—	—	4	0	0
–3	12	9	13	11	9	54	1–2	2	—	—	5	0	0
–4	10	3	7	14	6	40	Seg.‡	2	—	—	5	0	0
–5	10	9	6	9	6	40	Seg.	3	—	—	4	0	0
–6	7	5	6	4	4	26	3	2	—	—	4	0	0
–7	16	15	17	10	12	70	3	3	—	—	4	0	0
–8	14	7	13	8	10	52	Seg.	2	—	—	4	0	0
–9*	18	11	17	15	10	71	Seg.	2	5	0	3	0	0
–10*	16	13	15	9	8	61	4	2	—	—	4	0	0
P–6–1	6	1	7	8	10	32	4	3	—	—	5	0	0
–2	7	0	6	9	10	32	2	2	—	—	4	0	0
–3	3	0	3	2	4	12	Seg.	2	—	—	5	0	0
–4	3	0	2	8	10	23	Seg.	2	—	—	5	0	0
–5	0	0	0	4	2	6	4	1	—	—	5	1	20
–6	8	14	8	10	8	48	2	3	—	—	4	0	0
–7	9	15	10	12	10	56	3	2	—	—	5	5	100
–8	9	14	10	7	8	48	2	2	—	—	4	1	25
Lee parent	18	10	16	10	18	72	4	—	5	3	—	—	60
Victoria parent	11	6	13	7	10	47	1	—	2	0	—	—	0
Hairy Culberson parent	20	19	20	19	16	94	4	—	10	10	—	—	100
Lee × Victoria													
P–6–9	19	15	16	16	18	84	3	2	5	1	3	2	38
–10	18	15	18	15	16	82	4	2	5	3	5	1	40
P–22–1	17	16	20	16	12	81	Seg	2	10	4	4	2	43
–2	19	14	20	16	12	81	Seg.	2	5	0	4	2	22
–3	16	13	18	12	10	69	4	2	—	—	5	5	100
–4	14	13	13	8	8	56	Seg	2	—	—	4	4	100
–5	17	12	17	12	10	68	4	3	—	—	3	2	67
–6	12	7	10	14	8	51	3	0	—	—	4	4	100
–7	15	13	15	10	12	65	2	2	5	5	4	1	67
–8	10	6	12	6	4	38	Seg.	2	5	2	5	5	70
–9	18	14	18	19	12	81	2	2	5	4	4	4	89
–10	18	14	20	16	10	78	3	2	5	4	5	4	80

TABLE 4.—*Reaction of selections from Lee × Victoria and Hairy Culberson × Victoria oat crosses grown in the greenhouse at Ames, Iowa, and the Arlington Experiment Farm, Arlington, Va., to crown rust and smut infection at both stations, and to freezing at Ames, 1935–36.*

Varieties crossed and progeny No.	Av. 5- and 10-day condition indices (Ames)†						Reaction to physiologic race 1 of crown rust at		Reaction to smut at				
	Freezing experiment No.					Total	Ames (seedling)	Arlington (adult)	Ames		Arlington		Total smutted, %
									Plants		Plants		
	1	2	3	4	5				Grown, number	Smutted, number	Grown, number	Smutted, number	
-11	17	14	19	14	18	82	2	2	10	7	5	4	73
-12	19	13	20	15	16	83	2	0	5	1	5	5	60
P-30-1*	18	12	20	18	16	84	2	2	5	0	4	0	0
-2	15	11	15	14	8	63	2	2	5	0	5	1	10
-3*	17	13	16	12	6	64	1	1–2	5	0	4	0	0
-4*	13	12	15	14	8	62	1	2	5	0	4	0	0
P-32-1	15	10	12	11	6	54	2	3	—	—	5	5	100
-2	14	10	12	10	8	54	2	1–2	—	—	4	1	25
-3	16	15	18	15	14	78	Seg.	1–2	5	0	5	3	30
1-4*	16	17	18	16	14	81	2	1–2	5	0	5	0	0
-5	12	12	10	12	8	54	2	2	—	—	3	3	100
-6	13	10	12	6	4	45	2	2	—	—	4	0	0
-7	15	13	13	9	4	54	2	2	—	—	5	0	0
-8	15	15	15	16	8	69	2	2	5	2	3	0	25
P-33-1	19	14	18	12	14	77	3	2	—	—	4	3	75
-2	19	14	18	12	16	79	3	2	—	—	4	4	100
P-34-1*	13	16	17	16	12	74	Seg	2	5	0	4	0	0
-2*	13	15	15	16	10	69	2	2	—	—	2	0	0
-3*	15	14	15	15	10	69	2	2	—	—	4	0	0
Lee parent	14	16	15	19	16	80	4	—	5	5	—	—	100
Victoria parent	8	7	9	10	8	42	1	—	4	0	—	—	0
Hairy Culberson parent	19	18	20	20	18	95	4	—	5	5	—	—	100
Lee × Victoria													
P-34-4	2	5	4	7	2	20	Seg	2	—	—	3	0	0
-5	11	11	10	12	8	52	2	0§	—	—	3	—	0

–6*	18	14	18	18	16	84	2	1	5	0	4	0	0
–7*	17	13	16	13	16	75	2	1	–	–	3	0	0
–8	9	0	5	8	6	28	Seg.	3	–	–	5	0	0
–9*	16	14	18	18	17	83	Seg.	1-2	5	0	5	0	0
–10*	15	11	18	17	15	76	4	0	5	0	5	0	0
P–38–1*	10	6	10	14	12	52	4	0	–	–	4	0	0
–2	11	8	10	12	14	55	Seg.	2	2	0	4	0	0
–3*	14	10	15	14	10	63	Seg.	1	1	0	4	0	0
–4	13	8	12	10	8	51	2	1	–	–	5	0	0
–5	10	0	10	6	2	28	2	1-2	1	0	1	0	0
–6	9	0	10	6	4	29	2	1	1	0	3	0	0
–7*	15	10	15	14	16	70	Seg.	1	5	0	2	0	0
P–39–1	16	12	17	15	16	76	2	2	5	3	3	3	75
P–40–1	15	12	15	10	8	60	3	–	5	2	–	–	40
–2	10	0	10	8	6	34	2	–	2	0	–	–	0
–3	7	0	5	4	3	19	3	–	–	–	–	–	–
–4	8	0	5	10	10	33	3	–	2	1	–	–	50
–5	10	0	8	12	6	36	2	–	1	0	–	–	0
Hairy Culberson × Victoria													
P–43–1	15	12	18	10	14	69	2	2	5	0	5	0	0
–2	12	10	12	8	6	48	2	1	1	0	4	0	0
–3*	15	10	20	12	14	71	2	1	5	0	4	0	0
–4	14	8	15	10	10	57	2	1	3	0	2	0	0
–5	9	0	10	11	10	40	2	1	3	0	4	0	0
–6	10	6	12	10	8	46	2	2	4	0	4	0	0
–7*	15	10	18	10	14	67	2	1-2	5	0	4	0	0
–8	10	8	13	10	6	47	2-3	1	5	0	5	0	0
–9	9	0	6	8	4	27	2-3	2	–	–	3	0	0
–10	7	2	5	10	4	28	2-3	0§	–	–	5	0	0
–11	6	4	14	10	12	46	2	0§	–	–	3	0	0
Lee parent	15	10	12	14	14	65	4	–	5	5	–	–	100
Victoria parent	4	0	10	8	6	28	1	–	3	0	–	–	0
Hairy Culberson parent	18	16	20	15	16	85	4	–	10	10	–	–	100
Hairy Culberson × Victoria													
P–43–12	15	12	15	10	14	66	2-3	3	5	0	5	0	0

TABLE 4.—*Reaction of selections from Lee × Victoria and Hairy Culberson × Victoria oat crosses grown in the greenhouse at Ames, Iowa, and the Arlington Experiment Farm, Arlington, Va., to crown rust and smut infection at both stations, and to freezing at Ames, 1935–36.*

Varieties crossed and progeny No.	Av. 5- and 10-day condition indices (Ames)† Freezing experiment No. 1	2	3	4	5	Total	Reaction to physiologic race 1 of crown rust at Ames (seedling)	Arlington (adult)	Reaction to smut at Ames, Plants Grown, number	Ames, Plants Smutted, number	Arlington, Plants Grown, number	Arlington, Plants Smutted, number	Total smutted, %
−13	13	9	15	6	4	47	2–3	1–2	5	0	2	0	0
−14*	15	12	15	12	12	66	2–3	2	1	0	2	0	0
−15*	16	12	15	14	12	69	2	2	—	—	2	0	0
−16	10	8	10	12	14	54	2	0	—	—	5	0	0
−17*	12	10	15	14	12	63	1	0	—	—	5	0	0
−18	11	6	12	11	12	52	2	2	10	0	5	0	0
−19	10	10	10	9	8	47	2	2	5	0	5	0	0
−20	12	7	12	12	10	53	Seg	2	—	—	2	0	0
−21*	13	8	14	12	14	61	Seg.	2	5	0	2	0	0
−22*	16	10	12	18	10	66	1	0	5	0	5	0	0
−23	4	2	4	10	4	24	2	0	—	—	4	0	0
−24	10	4	6	10	6	36	2–3	2	—	—	4	0	0
P-44-1	14	18	13	14	12	71	2	2	—	—	2	2	100
−2	13	16	13	14	18	74	1	2	—	—	3	3	100
−3	11	10	8	12	9	50	2	0	—	—	3	3	100
−4	11	10	10	13	8	52	Seg.	0	—	—	4	0	0
−5	13	8	12	13	8	54	Seg	1–2	1	0	5	0	0
−6	13	10	15	13	16	67	2	2	—	—	4	4	100
−7	11	6	8	14	16	55	2	1	—	—	5	0	0
−8	10	4	10	13	15	52	2	2	5	0	4	0	0
Lee parent	12	14	10	14	12	62	4	—	5	5	—	—	100
Victoria parent	5	0	6	7	8	26	1	—	2	0	—	—	0
Hairy Culberson parent	17	12	20	15	18	82	4	—	5	5	—	—	100

*Families starred represent those from which further selections were grown in F_4 in 1936 in the field at Aberdeen, Idaho. (See Table 5.)
†In each experiment the selections were grouped for freezing as follows: 1–44, 45–78, 79–112, 113–139. As corrections were not made by adjusting all averages and totals to an average check, comparisons should be made only within each group.
‡Seg. = segregating.
§Dried up.

experiments conducted during the winter of 1935–36, there was considerable variation in the reaction of the selections in the different tests. This variation for the different groups within each experiment and between the different experiments is doubtless due largely to variations in the conditions under which the lots were hardened previous to freezing, and possibly to slight differences in the ages of the plants. Within any one experiment all of the seed was sown at the same time and the plants were maintained under the same conditions until the first group was placed in the freezing chamber. Also, the different groups of selections (Table 4, footnote 2) usually were placed in the freezing chamber on successive days. There was, however, a lack of uniform sunlight during the winter of 1935–36, owing to periods of cloudy weather, and this variation in light intensity appeared to account for most of the variation in average condition value of the plants in the various groups and experiments. The effect of reduced light intensity during the hardening period on the cold resistance of oat varieties has been reported by Murphy (3, pages 68–70).

Further evidence of transgressive segregation for resistance to cold is found in Table 4. Among 40 progenies of the cross X S1110 tested in F_3, 9 appeared superior in cold resistance to the winterhardy parent variety. Selections from only four of these progenies were tested in F_5, the remaining ones being discarded in F_3 and F_4 either because of susceptibility to crown rust or inferior grain characters. The four progenies continued into F_5 were P–1, P–30, P–33, and P–39 Of 20 selections from P–1 tested, 19 were more cold resistant than Lee. Apparently this progeny is nearly homozygous for a type of cold resistance slightly superior to that of either parent Only one of the four selections from P–30 was superior to Lee for cold resistance. This progeny possibly was heterozygous for this superior type of cold resistance Two selections from P–33 were tested and both were more cold-resistant than Lee. Only one selection of P–39 was included in the F_5 tests and it was slightly inferior to Lee for cold resistance. Altogether 37 of the 87 selections of X S1110 tested in F_5 were superior to Lee for cold resistance, and 22 of these were from similar F_3 progenies, while 11 were from progenies that were equal to or only slightly inferior to Lee in F_3.

Reaction of selections to race 1 of crown rust.—It should be noted from the outset that at Ames readings were made on seedling plants in the 1-leaf stage of development, while at the Arlington farm readings were made on adult plants approaching maturity. In general, there is a good agreement in the results, although the progenies were grown at two widely separated locations and the readings were made by two different individuals.[5] There are a few families in which the results are widely divergent. These variations probably are due mainly to (a) wide difference in age of plants, (b) slight differences in temperature (Ames greenhouse was controlled at 60° to 65° F, while the Arlington farm greenhouse temperatures were held at 55° to 65° F), and (c) presence of occasional heterozygous plants. Murphy (2) studied the relation of temperature and stage of development of oat

[5]Credit is due to H. B. Humphrey for making the inoculations and readings of crown rust at the Arlington Experiment Farm

varieties to their reaction to physiologic race 1 of crown rust. He found that the reaction of 14 oat varieties to race 1 was not greatly influenced by stage of growth or by temperature, although there was a tendency toward increase in susceptibility at higher temperatures. The data presented in Table 4 support the belief that in most cases resistance in the seedling stage is analogous to that in the adult stage. This should make it possible to greatly increase the amount of material that may be handled at a decidedly lower cost.

Reaction of selections to smut.—The results obtained on the reaction of these selections to loose smut are almost equally consistent. In 8 of the 70 duplicated tests smut was observed in a selection at one station and not at the other. Over 50% of the selections showed complete resistance to smut in the greenhouse tests. Unfortunately, because of the necessity of limiting space at all times in greenhouse cultures, the number of plants per selection was very small; therefore, one smutted plant indicates in some cases a rather high percentage of infection. The consistent high susceptibility of the susceptible parent varieties indicates, however, that conditions were very favorable for infection on highly susceptible plants.

On the basis of families, some were consistently highly susceptible to smut and others were consistently highly resistant. Of the 123 selections tested, 77 were resistant to smut. Unfortunately, not all of these were desirable from the standpoint of cold resistance, crown-rust resistance, and desirable grain characters. Thirty-three of the 77 smut-resistant selections were advanced to the F_6 generation for testing under field conditions in 1936.

F_6 POPULATION

As previously stated, progenies were grown from 33 selections in the F_6 at the Aberdeen Substation in 1936. All seed was hulled and inoculated with smut spores from Lee oats. Unfortunately, rather unsatisfactory results were obtained owing to poor germination of the seed. Because of late maturity in the greenhouse it was not possible to allow the seed to dry sufficiently long after harvesting before seeding at Aberdeen. Furthermore, the late spring at Aberdeen was warmer than usual, which was not favorable to these late-sown, winter-type oats. Colder weather immediately following seeding, such as usually obtained in early May at Aberdeen, probably would have resulted in a higher germination. A few of the plants were so late that they failed to produce seed and hence were lost. However, seed was obtained from some plants of nearly every family for further experimentation. The resistance of the selections to smut, together with notes on plant development in the different progenies, is shown in Table 5.

From Table 5 it will be seen that smutted plants occurred in 6 of the 33 families grown. The F_4 and F_5 progenies had been subjected to smut infection and it was believed that nearly all susceptible segregates had been eliminated.

As previously mentioned, it will be noted that the number of plants was very small. From 20 to 30 seeds were sown in most rows. The

TABLE 5.—*Reaction of selections of Lee × Victoria and Hairy Culberson × Victoria oat crosses from F_5 families that were resistant to crown rust, smut, and cold in greenhouses at Ames, Iowa, and the Arlington Experiment Farm, Arlington, Va., in the winter of 1935–36 to smut inoculation and to climatic conditions at the Aberdeen Substation, Aberdeen, Idaho, in summer of 1936.**

Varieties crossed and progeny number in F_5	Total 5- and 10-day condition indices (Ames) 1935–36†	Reaction of F_6 progenies to smut inoculation and climate in 1936		
		Plants grown		Behavior of progenies
		Total	Smutted	
Lee parent	70	38	38	Normal
Victoria parent	35	31	0	Normal, very late
Hairy Culberson parent	89	0‡	0	———
Lee × Victoria				
P-1-1	62	20	0	Variable
-7	91	36	0	"
-10	95	19	2	"
-13	91	36	6	Normal
-14	84	23	0	"
-18	92	57	0	"
-19	96	29	1	———
-20	95	35	7	———
P-5-1	60	4	0	Very late
-2	76	10	0	Variable
-9	71	13	0	"
-10	61	3	0	"
P-30-1	77	19	0	Normal
-3	58	18	0	Variable
-4	57	25	0	Normal
P-32-4	74	3	0	"
P-34-1	68	34	0	"
-2	63	11	0	"
-3	63	25	0	———
-6	75	18	0	Normal
-7	67	23	0	Early
-9	74	36	0	Variable
-10	69	37	0	"
P-38-1	47	42	0	"
-3	56	48	0	"
-7	63	31	0	"
Hairy Culberson × Victoria				
P-43-3	64	27	0	Normal
-7	60	32	0	Variable
-14	74	24	0	Very late
-15	77	26	0	———
-17	70	34	1	———
-21	68	21	1	———
-22	74	44	0	Normal

*For detailed data on unadjusted plant condition values and crown rust reaction, see Table 4, page 628.

†These totals were corrected by adjusting them to the average total condition values obtained for the parent varieties Lee, Victoria, and Hairy Culberson in all tests.

‡Seed of another variety inadvertently sown.

poor germination greatly reduced the value of the 1936 experiment at Aberdeen. The great variation in plant development in these progenies also resulted in some plants failing to produce seed that might

have been the most desirable from an economic standpoint. Regardless of the poor stand and the rather unfavorable conditions for oats of this type that prevailed at Aberdeen in the late spring of 1936, many plants were obtained from the most promising smut-resistant families that produced grain of good quality.

DISCUSSION

So far the results obtained from these investigations for the development of winter oats resistant to crown rust and smut are exceedingly encouraging. The use of artificial freezing for the immediate elimination of the tender seedlings from hybrid progenies probably will make possible much more rapid progress in breeding for cold resistance.

The results on relative resistance of these selections to crown rust and smut are in accord with those obtained from hybrid selections of strictly spring oats. It is evident that in many lines high resistance to the one disease has been combined with similar high resistance to the other. Furthermore, some of these strains also appear to carry the cold resistance of the Lee and Hairy Culberson varieties, and, therefore, should be of considerable agronomic value for fall seeding, although this is yet to be determined. However, it appears that before marked progress can be made in breeding for greater winter resistance in oats it is imperative that greater basic resistance to cold be obtained by the discovery or breeding of hardier types.

SUMMARY

Results on the reaction of selections from Lee × Victoria and Hairy Culberson × Victoria oat crosses to cold (freezing), crown rust, and smut under greenhouse, laboratory, and field conditions are presented for the F_3, F_4, F_5, and F_6 generations.

Forty-seven F_2 plants of approximately 600 that were marked as showing a tendency toward a winter habit in the seedling stage were used as foundation stocks.

A tendency was expressed for transgressive segregation with respect to cold resistance in the Lee × Victoria cross. This tendency was not evident in the Hairy Culberson × Victoria cross, but the population studied was very small. It also is possible that Victoria contributes no cold resistance when crossed on Hairy Culberson.

Under freezing-chamber conditions further evidence of transgressive segregation for resistance to cold in the F_5 generation was indicated. Thirty-seven of the 87 selections of the Lee × Victoria cross were superior to Lee for cold resistance.

The distribution of F_3 plants on the basis of their reaction to crown rust under greenhouse conditions suggests a genetic ratio of 1:2:1 in the F_2 for resistance, heterozygosity, and susceptibility. Most F_4 families of both crosses showed satisfactory resistance to crown rust.

Fairly close agreement in resistance to crown rust was obtained in sister progenies grown simultaneously in greenhouses at Ames, Iowa, and Arlington, Va. The data also support the belief that in most cases resistance to crown rust in the seedling stage is analogous to that of the adult stage.

Smut occurred in only two F_4 families of the Lee × Victoria cross and in none of the Hairy Culberson × Victoria combination. Of the 123 selections of both crosses tested in the F_5, 77 were resistant to smut at both Aberdeen, Idaho, and Arlington, Va. Results on the reaction of these selections to loose smut at both locations were almost equally consistent.

Under field conditions at Aberdeen, Idaho, in 1936 smutted plants appeared in 6 of 33 F_6 progenies. Many plants from the smut-free and crown-rust resistant families were promising in grain characters. These are being tested further.

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CERTAIN CHARACTERS OF COTTON FIBER AS AFFECTED BY PLAT PLACEMENT[1]

G. N. STROMAN[2]

SOIL variation in the irrigated sections of New Mexico creates a great problem in the production of cotton with fiber of uniformly high quality. It is commonly known by farmers that land of poor fertility produces cotton of poor quality. Reynolds and Killough (3)[3] reported that the application of potash tended to reduce the length of fiber and that rainfall was positively correlated with length of lint at College Station, Texas. Vilbrandt and Murphy (6) state that fibers of cotton grown on light land or badly washed land were $\frac{1}{16}$ inch to $\frac{1}{8}$ inch shorter than those of cotton grown on stiff land. Work by Bartholomew and Janssen (1) indicated that fertilizers may increase the size of the boll as well as the number of bolls.

From this report it will be noted that, along with yield, the length and uniformity of the fiber are affected by variation of soil, as shown by different placements of plats.

MATERIALS AND METHODS

In the regular progeny test block at the New Mexico Experiment Station each tenth row is planted to College Acala, the variety commonly grown in New Mexico. Only 8 of these rows in 1933, 7 in 1934, and 10 in 1935 were used to obtain the character percentage of 1 1/8-plus fibers; therefore, the data herein reported are on these checks only. The characters used in addition to percentage 1 1/8-plus fibers are calculated yield and the classer's length.

The calculated yield was obtained by multiplying the number of bolls per plant by the weight per boll and is recorded in grams of lint per plant. The classer's length is the length after ginning, as classed by the El Paso office of the Bureau of Agricultural Economics, U. S. Dept. of Agriculture. The percentage of 1 1/8-plus fibers is the percentage by weight of the fibers that are 1 1/8 inches or longer, according to the fiber sorter data. These characters have been described in detail in a previous publication (5).

The check rows used in 1933 and 1934 were random rows located at various places within the field, but in 1935, while they were random rows, they covered the field from one side to the other. They were planted to the same seed and given the same treatments as to irrigations, cultivations, and spacing. The spacing was one plant per hill with 20 inches between hills.

The analysis of variance and covariance is according to Fisher (2) and Snedecor (4). The first 10 plants in regular order of each check row were used in computing these data.

THE DATA

The sum of squares and the mean squares for total, between means of rows, and within rows are shown for 1933 in Table 1; for 1934, in Table 2; and for 1935, in Table 3; where A is yield in grams per plant,

[1]Contribution from Department of Agronomy, New Mexico State College, State College, N. M. Received for publication April 1, 1937.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 643.

B is length of lint in thirty-seconds of an inch, and C is percentage 1⅛-plus fibers.

It will be noted from Table 1 that there is no significant indication that yield was affected by the placement of these check rows in 1933. However, length of lint shows a very significant mean square between means of rows when compared with the within rows mean square. Also, the mean squares of percentage of 1⅛-plus fibers show that this character is affected by placement in the field.

TABLE 1.—*The sum of squares and the mean squares for the different sources of variation of eight check rows in 1933 as to yield (A), length of lint (B), and percentage 1⅛-plus fibers (C).*

Source of variation	Degrees of freedom	Sum of squares			Mean square			F values		
		A	B	C	A	B	C	A	B	C
Total. . . .	79	79548	63.80	3668	1007	0.81	464	1.0	4.3	13.6
Between means of rows	7	7916	50.00	1241	1131	7.14*	177*	1.1	37.6	5.2
Within rows. .	72	71632	13.80	2427	995	0.19	34	—	—	—

*Significant mean square.

In the 1934 data as shown in Table 2 there is a highly significant mean square of yield in the between means of rows. This is what would be expected rather than that which was found in the 1933 data. Also, both length of lint and percentage of 1⅛-plus fibers had a highly significant mean square, a fact which seems to show that these characters do vary with the fertility of the field.

TABLE 2.—*The sum of squares and the mean squares for the different sources of variation of seven check rows in 1934 as to yield (A), length of lint (B), and percentage of 1⅛-plus fibers (C).*

Source of variation	Degrees of freedom	Sum of squares			Mean square			F values		
		A	B	C	A	B	C	A	B	C
Total. . .	69	143534	11.84	874	2080	0.17	13	1.7	4.2	1.4
Between means of rows. .	6	68375	9.14	328	11396*	1.52*	55*	9.6	38.0	6.1
Within rows .	63	75159	2.70	546	1193	0.04	9	—	—	—

*Significant mean square.

In 1935, according to Table 3, the mean square of yield and length of lint in the between means of rows group is highly significant. However, the mean square of the percentage 1⅛-plus fibers of this group is not significant. It is well to note again that the rows in this year more nearly covered all the variation of the breeding block field than was the case in the previous year. However, the fertility of the field used this year did not vary so greatly as did that of the field previously used. The size of the standard deviation for yield of the within

rows group, or that of experimental error, was actually larger than in the other years, i. e., 45.0 ± 3.4, compared with 31.5 ± 2.6 for 1933 and 34.5 ± 3.1 for 1934. The mean square of the between means of rows was 6.1 times that of the mean square within the rows, but in 1934 this group was 9.6 times that of the error. However, in both years these mean squares were significant, as was to be expected.

TABLE 3.—*The sum of squares and the mean squares for the different sources of variation of ten check rows in 1935 as to yield (A), length of lint (B), and percentage of 1⅛-plus fibers (C).*

Source of variation	Degrees of freedom	Sum of squares			Mean square			F values		
		A	B	C	A	B	C	A	B	C
Total.	99	293182	87	5575	2961	0.88	56	1.5	4.6	1.0
Between means of rows ..	9	111244	70	463	12360*	7.78*	51	6.1	40.9	1.1
Within rows.	90	181938	17	5112	2022	0.19	57	—	—	—

*Significant.

The highly significant mean square of length of lint in the means of rows group in all 3 years seems to prove that the length of fiber varies with the fertility of the soil.

However, the low errors as shown by the within rows mean square may be explained by the human element of the classer in judging all plants of a certain row as being of the same length. The classer did know that the samples of a row came from one row, but he did not know which were the check rows. Therefore, it appears that there must have been a difference in the length or character of the fiber of these rows as grown in different parts of the field.

The percentage of 1⅛-plus fibers in 1935 did not show any difference due to plat placement in the field as it did in 1933 and 1934. The only explanation of this is that seasonal influences may have in some way equalized these differences.

RELATIONSHIPS

The covariance as indicated by correlation coefficients according to the different sources of variation is shown in Tables 4, 5, and 6.

TABLE 4.—*The relationships of yield (A) length of lint (B), and percentage of 1⅛-plus fibers (C), according to different sources of variation within eight random check rows in 1933.*

Source of variation	Degrees of freedom	Sum of products			Correlations		
		AB	AC	BC	AB	AC	BC
Total.......	69	477.90	1162.70	231.60	0.21	0.07	0.48
Between means of rows.	7	444.20	1377.92	178.56	0.71	0.44	0.72
Within rows	72	33.70	-215.22	53.04	0.03	-0.02	0.29

The significant correlations shown in Table 4 are AB, between yield and length of lint, and BC, length of lint and percentage 1⅛-plus fibers in the between means of the rows; however, they are not highly significant. Also, it is hardly significantly different from the within rows correlation coefficient, the z difference being nearly twice as large as its standard error, .84 ± .46. The correlation coefficient between length of lint and percentage of 1⅛-plus fibers in between means of rows is not highly significant and does not differ significantly from its coefficient of the within rows, the z difference being .61 ± .46.

The 1934 relationships given in Table 5 show for the total group highly significant correlations between all three characters However, only one of these, yield by length of lint (AB), differs from the error coefficient by a significant amount, z (diff.) = .37 ± .18. In the between means of rows group the coefficients AB and AC are significant for six degrees of freedom. However, they do not, according to z (diff), differ by a significant amount from the within rows coefficients.

TABLE 5.—*The relationships of yield (A), length of lint (B), and percentage of 1⅛-plus fibers (C), according to different sources of variation within seven random check rows in 1934.*

Source of variation	Degrees of freedom	Sum of products			Correlations		
		AB	AC	BC	AB	AC	BC
Total . . .	69	633 51	3896 00	33.72	0 49	0.35	0.33
Between means of rows	6	560.51	3466 98	26.26	0 71	0.73	0.48
Within rows	63	73.00	429 02	7.46	0.16	0.07	0 19

In 1935, as shown by the data in Table 6, there is found no significant correlation coefficient with the exception of the coefficients AB and BC of the within rows group of — 22 and .23, respectively. However, the coefficient AB of the total variation group, according to the z test for difference, gives a difference of 39 ± .15 from the error group. Since it is twice as large as its standard error, it can be considered significant. As to just what this means, the writer cannot say at the present time.

TABLE 6 —*The relationships of yield (A), length of lint (B), and percentage of 1⅛-plus fibers (C), according to different sources of variation within ten check rows in 1935.*

Source of variation	Degrees of freedom	Sum of products			Correlations		
		AB	AC	BC	AB	AC	BC
Total	99	812	-2736	67	0.16	-0.07	-0.10
Between means of rows .	9	1206	-209	-2	0.43	-0.03	-0.01
Within rows . .	90	-394	-2527	69	-0.22*	-0.08	0.23*

*Significant.

DISCUSSION

It appears from the data that length of lint and percentage of 1⅛-plus fibers are affected by plat placement in the field, even where

there is not a great difference in soil fertility. Such effect by the plat placement may be due to variation in the soil and also possibly to varying amounts of irrigation water. This evidence is shown definitely in only one character, that of length of lint. Still, the character percentage 1 1/8-plus fibers gave a significant mean square in between means of rows in two out of three years tested. It is rather a disheartening picture to paint for the plant breeder, but this is the same situation that confronts the plant breeder in breeding for any yield character where land is very ununiform, as it is in southern New Mexico. It means that the plant breeder must use the best methods for precision in the field and in the laboratory. Plants that appear to be the best individuals for particular characters may in reality be the poorest. Just as the genotype of the individual is the important consideration, so will all these best individuals respond to favorable treatments. Nevertheless, the plant breeder is interested in the genotype that will give the best yield and the highest quality on any type of land on which the cotton happens to be planted. This appears to be a rather fantastic objective, but one entirely possible to attain.

In order to safeguard his progeny test, the cotton breeder can plant check rows closer together in the test for a standard of comparison with the different individuals of the progeny. In the cotton breeding work at this Station, one check row is placed in each plat of 10 rows. So far, this has been sufficient for all practical purposes, and comparisons of progenies are always made with the check row within the same plat as the progeny.

In regard to the relationships of the characters as shown by the correlation coefficients in the groups of different sources of variation, we have seen how this relationship is different in the different groups and also according to season. The evidence presented herein is not conclusive, but is, in fact, rather meager; however, it gives an indication that as certain characters change, according to the variation in the soil, so do the relationships of the characters. At least, heredity expresses itself according to the environment; therefore, it seems rather reasonable to suppose that certain character relationships would also change.

Unpublished data at this Station seem to show that fertilizer treatments and even irrigation treatments can change the relationships of the characters.

SUMMARY

An analysis of variance is shown on 8 check rows of 10 plants each in 1933, 7 check rows in 1934, and 10 such rows in 1935 The significant mean squares in the source of variation of the between means of rows seem to indicate that certain qualities of lint, as especially denoted by length of lint and percentage 1 1/8-plus fibers, are affected by the placement of plats. Such variation is probably due to ununiformity of the soil.

The relationships of the characters as shown by the correlation coefficient of the different sources of variation seem to change to some degree as the characters themselves are affected.

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NATURAL CROSS-POLLINATION STUDIES IN FIBER FLAX[1]

B. B. ROBINSON[2]

An understanding of the amount of natural cross-pollination that occurs is of fundamental importance in the improvement of fiber flax varieties as the amount of such crossing will influence the methods used in breeding and maintaining pure varieties. During the past 12 years, the writer has observed this source of error which enters into plant breeding nursery work and has results from 8 years testing to report of the frequency of such crossing.

Henry and Tu (1)[3] have reviewed the literature in this field and reported natural crossing results in flax which they obtained in Minnesota. A study of the literature shows that crossing has been reported by workers in India, England, Holland, Germany, France, Ireland, and the United States. Further, this literature reveals that the crossing reported was in most cases chance occurrences and, as far as could be determined, below 1%. Such a small percentage is similar to what has been reported in many common farm crops which we consider are normally self-pollinated. Henry and Tu found as much as 1.71% crossing occurring between two flax varieties in Minnesota. Since their article appeared, the Imperial Bureau of Plant Genetics in a publication on Plant Breeding in the Soviet Union (2) has indicated that flax is subject to cross-pollination up to 40%. No results or discussion are given in reference to this high figure.

METHOD OF TESTING

The writer's original studies were mainly confined to counting rogues found in different varieties and testing these rogues for purity. In 1926, 1927, and 1928, a few parallel rows of flax were grown 1 foot apart containing alternately white- (Ottawa 770B) and blue- (Saginaw) flowering varieties These were planted in triplicate tests. Because of the differences in the time of maturity of these varieties, as well as the limited space which was used for testing, the F_1 and F_2 generations in the greenhouse, the results were very limited the first three years.

In 1929 and 1931 a new test was conducted in Michigan and a similar test was carried on the following three years in Oregon. No field experimental work was carried on in 1930. In these tests white- (Ottawa 770B in 1929 and Pinnacle 1931 to 1934) and blue- (J. W. S.) flowering varieties were planted alternately in triplicate tests 25 feet long and spaced 6, 12, 24, 36, and 48 inches apart. Each row was harvested and threshed separately. Sufficient seed from each row was obtained to plant 25 feet of row the following year. The varieties, Pinnacle and J. W. S., flowered approximately at the same time. It is possible that Pinnacle, the

[1]Technical paper No. 253, Department of Farm Crops, Oregon Agricultural Experiment Station, Corvallis, Ore The experiments were conducted in cooperation with the Division of Cotton and Other Fiber Crops and Diseases, U. S. Dept. of Agriculture. Received for publication April 7, 1937.

[2]Agronomist, Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The author is indebted to H. M. Brown of the Michigan Experiment Station for suggestions regarding the arrangement of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 649.

white-flowered variety, was a day or two later in maturing than J. W. S., but it is one of the earliest white varieties in the breeding nursery and averages several days earlier than Ottawa 770B.

In Michigan and Oregon, the process of fertilization appeared to be quite similar to that described by Tammes (3). The flax flowers, in general, were open and receptive to fertilization only part of one day. Several flower buds may appear on the same plant and these usually mature on different days. Different plants within a variety vary in flowering a few days; so the flowering period of a variety extends for two weeks or longer. Therefore, differences of a day or two in the beginning of flowering between different varieties does not eliminate possibilities of natural crossing.

CROSSING ON WHITE-FLOWERED VARIETIES

Blue flower color is genetically dominant to white flower color; so when crossing occurs on the white plants from the blue, the hybrids may be observed the next year in the F_1 generation These supposed hybrids were carefully tagged and at harvest the seed from each one saved separately for testing the next year. This was necessary to prove they were hybrids and not the result of mixture. Due to unfavorable climatic conditions and other causes in some years, not all of these supposed F_1 hybrids produced sufficient seed for blossom color segregation to be certain in the F_2 In fact, in some cases, no seed was obtained and in other cases the seed germinated and emerged so poorly that only one to a half dozen or more plants were obtained.

From tests conducted in 1926, 1927, and 1928, a total of 1,802 individuals were counted and these produced 45 supposed hybrids giving 2.50% crossing from blue onto white The results from succeeding years were more detailed, as they involved width of space between rows, and are given in Table 1 Of the 132 blue blossom plants counted in 1929 and 1931, only 121 produced progenies for the F_2 test. Of these, 24, or 19.8%, did not segregate. The possibility of segregation in the F_3 was not studied. In 1932, 1933, and 1934, 241 blue blossom plants were counted, but only 180 produced progenies in the F_2 of which 75, or 41.7%, did not segregate This shows that 80.2% in Michigan and 58.3% in Oregon of the blue blossom plants appearing in white varieties in the F_1 generation were definitely determined to be heterozygous and undoubtedly the result of natural crossing. If those which did not segregate were not of hybrid origin, the percentages in Table 1 are too large However, it is believed that they are approximately correct due to the higher percentages which are discussed in the next section and are shown in Table 2.

CROSSING ON BLUE-FLOWERED VARIETIES

In testing the crossing in blue- from white-flowered plants, it was necessary to grow progenies in the F_2 to obtain a segregation of blossom color within the progenies. From each triplicate row of blue-blossomed plants grown in the F_1, the seeds from 100 individual plants selected nearly at random were saved and these were grown separately in the F_2 to determine how many would segregate. The wording—nearly at random—is used in the preceding sentence because if the

TABLE 1.—*Amount of crossing in Michigan and in Oregon from blue-flowering onto white-flowering varieties.*

Distance rows apart, in.	Michigan								
	1929			1931			1929 and 1931		
	No. white	No. blue	%	No. white	No. blue	%	No. white	No. blue	%
6	760	7	0.91	2,670	18	0.67	3,430	25	0.72
12	738	11	1.47	2,688	25	0.92	3,426	36	1.04
24	447	5	1.10	2,441	27	1.09	2,888	32	1.10
36	298	3	1.00	2,609	18	0.69	2,907	21	0.72
48	673	5	0.74	2,398	13	0.54	3,071	18	0.58

Distance rows apart, in.	Oregon					
	1932			1933		
	No. white	No. blue	%	No. white	No. blue	%
6	4,981	30	0.60	4,737	50	1.04
12	5,288	26	0.49	4,569	15	0.33
24	4,897	8	0.16	4,881	8	0.16
36	5,000	12	0.24	4,559	9	0.20
48	5,139	8	0.16	4,529	18	0.40

Distance rows apart, in.	1934			1932, 1933, 1934		
	No. white	No. blue	%	No. white	No. blue	%
6	4,562	22	0.48	14,280	102	0.71
12	4,403	15	0.34	14,260	56	0.39
24	4,246	6	0.14	14,024	22	0.16
36	4,600	7	0.15	14,159	28	0.20
48	4,270	7	0.16	13,938	33	0.24

random plant selected had less than three seed bolls it was discarded and another plant selected with a greater number of seed bolls. The greatest number of seeds possible in a boll is only 10, while 7 or 8 is the usual case. By selecting plants with three or more bolls, one was assured of having approximately 21 to 24 seeds to grow in order to observe whether segregation would occur for blossom color. In spite of this care, in some progenies, often as low as 10 plants were obtained which number was hardly sufficient for an exact determination of the recessive which appears in a ratio of 1 to 3.

A total of 224 F_2 progenies, originating from tests conducted in 1926 and 1927, were grown and 8 of these segregated for blossom color indicating 3.57% crossing from white onto blue. The results from succeeding years being in greater detail are given in Table 2. Of the total of 3,000 progenies studied in 1929 and 1931, 64, or 2.13%, showed segregation and of the 4,500 progenies studied in 1932, 1933, and 1934, only 21, or 0.47%, showed segregation.

TABLE 2.—*Amount of crossing in Michigan and in Oregon from white flowering onto blue-flowering varieties.*

Distance rows apart, in.	Michigan								
	1929			1931			1929 and 1931		
	No. blue	No. blue-white	%	No blue	No. blue-white	%	No blue	No. blue-white	%
6	293	7	2 33	294	6	2 00	587	13	2 17
12	296	4	1.33	291	9	3 00	587	13	2.17
24	297	3	1.00	291	9	3.00	588	12	2.00
36	288	12	4.00	294	6	2.00	582	18	3.00
48	298	2	0 67	294	6	2 00	592	8	1 33

Distance rows apart, in	Oregon					
	1932			1933		
	No. blue	No. blue-white	%	No blue	No blue-white	%
6	300	0	0 00	294	6	2 00
12	299	1	0 33	299	1	0.33
24	299	1	0 33	300	0	0 00
36	300	0	0 00	300	0	0 00
48	298	2	0.67	298	2	0 67

Distance rows apart, in	1934			1932, 1933, 1934		
	No. blue	No. blue-white	%	No blue	No blue-white	%
6	298	2	0 67	892	8	0.89
12	298	2	0 67	896	4	0.44
24	297	3	1 00	896	4	0.44
36	300	0	0 00	900	0	0.00
48	299	1	0 33	895	5	0 56

VARIETAL DIFFERENCES

It will be noticed after studying Tables 1 and 2 that in 9 out of 10 of the summations there is a larger percentage of crossing on blue- than on white-blossom varieties. This was also true of the results obtained in 1926, 1927, and 1928. The exact explanation for this is not known. From 1926 to 1929, inclusive, Ottawa 770B was used as the white variety, while after 1929 Pinnacle was used The results were the same with the different white varieties as well as different blue-flowered varieties. However, it is possible that varietal differences may exist. Another explanation is that the slight difference in the time of flowering might have produced the discrepancies. This error would be less in the case of Pinnacle than Ottawa 770B as Pinnacle's flowering time is almost identical with the blue J. W. S. However, the greater amount of crossing on blue might influence one to believe that the

blue plants appearing in the F_1 of the white variety which did not segregate in the F_2 were, in many cases, true hybrids and that lack of sufficient number of F_2 plants did not allow the segregation to occur and be recorded.

REGIONAL DIFFERENCES

Tables 1 and 2 indicate that slightly less natural crossing occurs in Oregon than in Michigan. This may be due to climatic conditions. Flowering occurs in Michigan at a time when the humidity is higher than when flowering occurs in Oregon. It has been observed that when the weather is cool and humid, the flowers remain open longer and do not shed their petals as quickly as in warm, dry weather. In Michigan, observations would indicate that the flowers retain their petals on the morning they open probably an hour to two hours longer than in Oregon. The dropping of the petals might have some importance if flying insects were responsible for the work. Several insects have been reported as responsible for this work in Europe and it is known that insects work on flax in the United States. After the petals are shed, the sun may strike the anthers rapidly withering them, and thus insect transmission of pollen would be less likely.

The spacing of the rows undoubtedly influences the amount of crossing. The results are somewhat variable, but they tend to substantiate this point The amount of reduction due to spacing up to 4 feet is hardly sufficient to be of practical importance.

TOTAL CROSS-POLLINATION

Most writers assume that the percentage of natural cross-pollination within the variety is probably equal to the amount taking place between adjacent varieties If this is true then the percentage figures represent only half of the crossing actually occurring in flax. From the practical side of plant improvement the crossing within a variety which is already genetically pure has little importance. The plant breeder is concerned mainly with the crossing between varieties which is likely to prevent the continuation of purity once it has been attained.

HOW HOMOZYGOUS ARE VARIETIES?

No one has definitely stated that one-half, three, or some other low percentage of natural crossing between adjacent varieties is too much to hinder the carrying on of improvement by close nursery methods. However, state crop-improvement organizations in their inspecting and registering of elite farm crop seeds for planting frequently require less than 0.25% mixture of other varieties and seldom allow more than 1% mixture. In order for Canadian flax seed to be graded Registered No. 1, in reference to certification, it must not contain more than 2 seeds per ounce of other distinguishable varieties (4). Additional seed laws are as stringent for several other field crops. In fiber flax, there are approximately 7,000 seeds per ounce and a mixture of 2 seeds would be less than 28/1000 of 1%. If the word "distinguishable" was omitted, it is not likely that many varieties originating in

close nursery work could come up to such standards or even standards of 0.5%. It is fortunate that many crops, including flax to a slight degree, have some varietal characters which allow roguing. This allows purity as a distinguishable characteristic to come within our seed laws. Fortunately, too, in many crops, natural crossing is likely to produce little detrimental effect as the variety differences are minor.

In order to originate flax varieties, as well as other crop seeds, to measure up to high standards of purity which refer only to the maximum mixture allowable, it is believed to be very advisable by space isolation and bagging selections to prevent the occurrence of natural crossing as much as possible. It may be questionable whether the benefit derived from such space isolation is equal to the labor and expense of carrying on such work If care is used in preventing natural crossing, and if, in addition, roguing is employed daily over a 3-weeks' flowering period, it seems possible that selections may be maintained pure enough to come within the general interpretation of purity in existing seed laws

CONCLUSIONS

1 Natural crossing in flax has been reported as occurring in a number of countries, usually to a very small degree.

2. More crossing was observed to occur in Michigan and Oregon on blue-blossom varieties than on white-blossom varieties.

3 More natural crossing was recorded in Michigan than in Oregon.

4. The total crossing within and without the same variety may amount to 5 or 6% in Michigan and to 1 or 2% in Oregon.

5 It seems difficult to understand how varieties can be as pure as existing seed laws require if no precautions are taken to prevent natural crossing which occurs in nursery work.

6. Bagging of selections or space isolations, as well as intensive roguing, are the plant improver's method of attacking this difficult problem.

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THE NEED FOR STATISTICAL CONTROL IN SOILS EXPERIMENTS[1]

R. H. WALKER[2]

A REAL evolutionary development in the technic of agronomic experimentation has occurred since the first field experiments were conducted a hundred years ago by Bouissingault. This branch of research had its beginning, as did all others, in relatively crude observations. Only comparatively simple methods of experimentation, which were primarily of a demonstrational nature, were available for the greater part of the past century. Owing to the fact that gross experiments were probably economical and desirable in the early stages of this research, and that the more obvious hypotheses needed testing first, the prevailing methods seemed adequate and entirely satisfactory for the purpose. And it is very significant that many of the fundamental principles of sound soil management and crop production were developed by these methods of field experimentation.

In recent years, however, and since the more obvious of the agronomic principles have been demonstrated, we have been confronted with the more complex and intricate of the agronomic problems. Furthermore, the heterogeneity of apparently uniform areas of soils used for experimental purposes, which was not recognized nor fully appreciated until rather recently, has been found to contribute in large measure to the errors involved in field experiments. This situation necessitated and stimulated the search for refined technic and improved methods. Extensive and complete experiments were conducted by many agronomists toward this end with the result that the methods were greatly improved and the way opened for increasing markedly the precision of field experimental results.

Coincident with this development came a recognition of the necessity for a statistical analysis of the data of field experiments. Hence the statistician was asked to analyze data that had already been obtained. This necessitated the formulation of an estimate of error, which, in most cases, could not be obtained from the data available owing to the inadequacy of the experimental design. Unfortunately, this often involved the formulation of assumptions that were not supported by the facts and conditions of the experiment. The statistician was helpless in these cases, however, for it is obvious that he could not inject into his statistical procedure something that had been left out of the experiment by the agronomist. This in turn stimulated research on the part of the statisticians, and in many instances their work was coordinated with that of the agronomist. As a result of the combined efforts of these two groups of people, we now have principles of experimental design and appropriate methods of statistical analysis which will permit the formulation of an estimate of the experimental error from the experiment itself, and by means of which the significance of differences can be interpreted. It is now regarded

[1]Contribution from the Intermountain Forest and Range Experiment Station, Ogden, Utah. Also presented before the annual meeting of the Society held in Washington, D. C., November 20, 1936. Received for publication April 12, 1937.
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essential that the need for a statistical study of the data to be obtained should be given consideration in planning the design of the experiment.

By using these newer principles of experimental design and statistical methods, we can, first, increase the precision of our experiments; second, resolve the total variability of results into its respective components and thereby attribute the appropriate portions to the various factors included in the experimental design; third, obtain an unbiased estimate of the experimental error with which a valid test may be made of the significance of increases or decreases in yield owing to the soil treatments; and fourth, greatly increase the efficiency of our experiments both from the standpoint of time and labor expended and also the amount and quality of information derived therefrom.

Realizing that all these things are now possible, no one would doubt that we are entering into a new era of agronomic experimentation. It will be an era of opportunity and many of the difficult problems of the past will now be capable of solution. Information will be gained concerning the interaction of various forces, which in the past have only added confusion to our research, but which in the future will open before us many fundamental relations, and interrelations, of which we have not yet dreamed.

Particularly are we indebted to Dr. R. A. Fisher, and his associates, for the development of these principles and methods on a statistical basis and in such a manner that they may be applied practically to agronomic investigations. In the preparation of this paper, free use has been made of material in the books and papers of Dr. Fisher,[3] and for the suggestions and ideas obtained full credit is hereby acknowledged.

Before going into a discussion of the fundamental principles of these newer methods of experimental design, it is desired to point out briefly the almost universal heterogeneity of soils. Soil heterogeneity is not new to agronomists, but a full appreciation of its magnitude, of its character, and of its effects are essential to a full understanding of the need for statistical control in soils and in agronomic experiments in general.

The type of soil heterogeneity with which we are now concerned is not that between soil types and which is so obvious, but that which occurs *within* a soil type, and particularly that which occurs within comparatively uniform areas of a soil type that may be and usually are selected for experimental plats. This is the soil heterogeneity that is not so obvious, but which has a profound influence upon experimental results and which has led to so much confusion and contradiction. It is probably the major source of the variability observed in experimental results, and it is the factor toward the control of which so much research effort has been directed.

Comparatively uniform areas of soils may be heterogeneous in their physical, chemical, or biological characteristics, or the heterogeneity may result from variability in all of these factors, and this is usually

[3]FISHER, R. A. The Design of Experiments. Edinburgh: Oliver and Boyd. 1935.
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the case. Each of these types of heterogeneity are reflected in the yield of crops produced upon the soil, and it is the resultant of their effects that has been so troublesome in the conduct of field experiments and in the analysis of the data obtained.

Harris[4] studied the heterogeneity of a large number of experimental fields as indicated by the variance of crop yield upon different plats. He pointed out that the heterogeneity in crop yields, which is a resultant of soil heterogeneity, was a practically universal characteristic of the fields that had been used for agronomic experiments. He also emphasized the necessity for greater care in agronomic technic and more extensive use of the statistical method in the analysis of the data of plat trials in order to bring out their greatest value for the solution of agricultural problems. We now know soil heterogeneity to be a fact, but fortunately we now have principles of experimental design and methods of statistical analysis, which when properly used, will permit us to overcome the chaotic state in which this heterogeneity has held us in the past, and also to make deductions that are based on a valid test of statistical significance. It is to these principles of experimental design that attention will now be directed.

In order for an experiment to yield genuine information in and of itself, without the aid of extraneous data or personal experience and judgment, it must contain within itself the possibility of making a valid estimate of the experimental errors which actually affect the comparisons made. To illustrate, let us suppose that we wish to demonstrate the response of corn to an application of a phosphate fertilizer on a particular type of soil And suppose, for this purpose, that we distribute the fertilizer evenly over the entire experimental area. As we observe the corn throughout the growing period and at harvest time when the yield per acre is estimated, we may conclude, and with satisfaction, that the corn grew better and the yield was heavier as a result of the fertilizer treatment. In formulating this opinion, however, it is necessary for us to draw upon our previous experience in growing corn on a soil similar to this, if not on the same plat. Although we may be satisfied that the phosphate brought about a real increase in the yield of corn, this conviction is necessarily personal, and owing to the nature of the evidence, others who have not shared with us in our experience may not be so convinced. Some may hold the view that our judgment is biased. The experiment itself would not yield information to indicate what the yield of corn would have been on the same land and in the same season without the phosphate. Neither would our previous experience.

It is not assumed that any agronomist would conduct a fertilizer test in this manner, for it was early recognized in experimental work that the reservation of an untreated check plat alongside of the fertilized plat, and against which the fertilized plat could be compared without bias, would serve to increase the quality of the evidence obtained in the experiment and make it strictly objective. The general and rather extensive use of such check plats in agronomic experiments for this purpose is well known to each of us.

[4]HARRIS, J. ARTHUR. Practical universality of field heterogeneity as a factor influencing plot yields. Jour. Agr. Res., 19:279–314. 1920.

Although it is plainly obvious that check plats are essential to the making of unbiased comparisons in this experiment, it still is lacking in one element, which is perhaps not quite so obvious, but which is equally fundamental if the experiment is to make a genuine contribution of new knowledge in and of itself. And that is *replication* of the treatments. This is fundamental in all experiments.

In any experiment where heterogeneity is involved replication serves to accomplish two fundamental purposes. First, it diminishes the errors involved owing to soil heterogeneity or to any other source of variance; or in other words, replication serves to increase the precision of the experiment. Second, replication of the treatments serves to supply an estimate of error by which the significance of the comparisons is to be judged. Along with replication, however, it is equally essential that the replicated treatments be *randomized* in their location over the experimental area. Randomization is essential to guarantee the validity of the test of significance which is based on the estimate of error made possible by replication. When an experiment has been designed in such a manner as to give the proper consideration to these two elements, namely, *replication* and *randomization* we say it is self-contained. That is, it contains within itself the possibility of making a valid estimate of the experimental errors which actually affect the comparisons made. These two elements are absolutely fundamental in any experiment that is to make a genuine contribution of new knowledge and from which conclusions are to be drawn without bias or without the aid of extraneous data or personal experience and judgment.

Owing to the fact that these two elements are fundamental in all self-contained experiments, an attempt will be made to clarify the situation and show why they are so essential. This can be done by the aid of an illustration, using an experiment that was set up on a *randomized block* design.

In Fig. 1 there is shown a diagram of an experimental field which was set up in southern Iowa a few years ago. The purpose of the experiment was to determine the effects of various soil treatments on the yield of alfalfa. The specific treatments are not given here, but they are designated by the numbers 1, 2, 3, 4, 5, 6, and 7. It will be noted that there are seven different soil treatments and that each treatment occurs once and only once in each block. Each block therefore constitutes a complete replication of all treatments. There are six blocks of plats and therefore each treatment is replicated six times. It is important to observe also that the plats are distributed within the blocks strictly at random.

A detailed exposition of this experiment is not possible nor necessary here, but it is sufficient to indicate that when the results were obtained the data were analyzed by the analysis of variance. This is a simple arithmetic procedure by means of which the results may be arranged and presented in a single compact table which shows the structure of the experiment and the relative results in such a way as to facilitate the necessary tests of their significance. The structure of the experiment is determined when the experiment is planned, and it is specified by the number of degrees of freedom, or of independent

comparisons which can be made between the plats, or relevant groups of plats.

In this particular experiment there are 42 plats. The total number of degrees of freedom, therefore, is 41. Among seven different treatments, six independent comparisons can be made, and among the six blocks of plats, five comparisons can be made. There are, therefore, six degrees of freedom for soil treatments and five for blocks. The re-

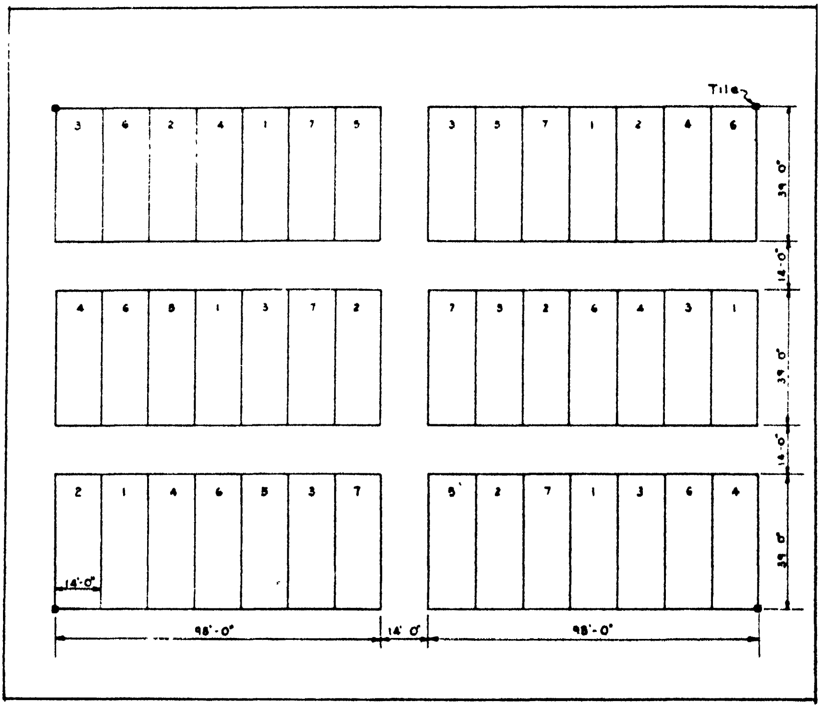

FIG. 1.—Diagram of experimental field with randomized block design. Each treatment occurs once in each block and the treatments within blocks are distributed at random.

maining 30 degrees of freedom, which are not accounted for by the treatments and blocks, are due simply to differences in fertility between different plats within the same block and are therefore available for providing the estimate of error.

The completion of the analysis of variance, when the yields are known, must be strictly in accordance with the structure imposed by the design of the experiment and consists in the dividing of the sum of squares of deviations from the mean into the same three parts as those into which we have already divided the degrees of freedom. The data obtained in the present experiment have been so analyzed and are shown in Table 1. In this particular experiment no significant differences in yields of alfalfa resulted from the soil treatment.

TABLE 1.—*Analysis of variance of alfalfa yields.*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	41	7,966	——
Between blocks	5	1,881	376
Between treatments	6	1,808	301
Remainder (error)	30	4,277	142.5

The total variance in yields owing to soil treatments, soil heterogeneity, or to any other cause is shown in the total sum of squares. By the analysis of variance, the portion of the variance due to soil variation between the different blocks is separated and placed by itself. Likewise, the variance due to soil treatments is also separated from the whole. It is therefore possible to ascribe a definite proportion of the total variance to these important members of the experiment, the number of degrees of freedom being the sole determining factor as to how much of the variance may be ascribed to each. The variance remaining after that due to differences between blocks and treatments is segregated, is the portion which is not accounted for and represents the discrepancies in yield between the different plats within a block. This then serves as a measure of the experimental error and is used in making the test of significance.

Returning to the two fundamental elements of a self-contained experiment, namely, replication and randomization, it has been pointed out that replication has two purposes. The first is to diminish the error or to increase the precision of the experiment. This has been widely recognized, though the manner in which it does so has not always been well understood.

It has been demonstrated repeatedly that small and compact areas of land are generally less heterogeneous than larger ones. It is obvious therefore that if a given experimental area were divided into smaller units, such as was shown in the randomized block design, the differences in soil fertility between blocks would constitute the larger proportion of the total variability, whereas those differences between plats within a block would be comparatively small. By replication of the plats in blocks, therefore, each block constituting a complete replication of all treatments, and by the analysis of variance, the differences between blocks are eliminated from the experimental error, which then is dependent on only the differences in fertility between plats within blocks. Consequently, if the larger portion of the total variability due to soil heterogeneity is eliminated, the precision of the experiment is increased.

By using the randomized block arrangement the experiment may be extended to different fields, or to different soil types, and while more information is being obtained the differences between blocks will be eliminated and the precision of the experiment will be increased.

In this connection, however, it must be kept in mind that, although increased replication will serve to increase the precision of the experiment, it is not the only means of obtaining this result, and therefore, the number of replications should not be increased unduly when other

methods may attain this end with less expenditure of time and labor. In actual field experimentation the experimenter must determine for himself the number of replications practicable for the precision required by the experiment.

It was at one time thought that extremely large numbers of replications were necessary to obtain reliable results. However, ideas on this point have changed somewhat, for it is possible with some of the newer types of experimental design to obtain *hidden replication* and thereby obviate the necessity for so many direct replications.

The second, and probably the main, function of replication is to provide the experiment with its own appropriate estimate of error by which the significance of the comparisons is to be judged. This is a function which nothing but replication can perform. It is just as important to see that the estimate of error is unbiased, that is, neither too large nor too small, as it is to plan the experiment in such a manner that *direct comparisons* and estimates can be made without bias. For without an unbiased estimate of error, no valid tests of significance can be made, nor can one tell what weight to give to the evidence of the experiment when it differs in its result from others of a like kind.

The means by which an unbiased estimate of error is attained is by *randomization of the replicated treatments.* The real errors in experimental results arise from differences in fertility among the plats, or among the groups of plats, which are treated differently. The estimate of error is obtained from the discrepancies among the plats treated alike, but it is to be applied to differences observed between sets of plats treated differently. Consequently, we have only to make sure that any two plats which may be treated alike have the same probability of being treated alike, and the same probability of being treated differently in each of the ways in which this is possible. This is accomplished by randomizing the treatments as illustrated in Fig. 1.

This is the place one frequently runs into difficulty in setting up an experiment. Those who have been conducting field experiments are quite generally convinced of the desirability of replicating the treatments, but when it comes to distributing the treatments at random over the experimental area, they sometimes object. This is done because it is assumed that the purpose of randomization is the same as that of replication, namely, of increasing the precision of the experiment. It should be made clear, however, that the purpose of randomization is not to increase precision, but only to ensure that whatever precision the arrangement is capable of giving is neither overestimated nor underestimated.

SUMMARY

1. When field experiments are being conducted it is of primary importance to consider the soil type on which the tests are being made; for, although results obtained on one soil type may apply in principle to other soils, they cannot be used as a basis for specific recommendations as to the management of other soil types.

2. Owing to the large influence climatic variations have on any field experiment, the tests should be conducted over a period of years

in order that the errors or variations contributed by the climatic changes may be properly evaluated.

3. The two fundamental principles of good experimental design, *replication* and *randomization*, should be given full consideration if the experiment is to give genuine information without the aid of extraneous data or personal experience and judgment. Replication will serve, first, to increase the precision of the experiment, and second, to supply an estimate of error by which the significance of the comparisons is to be judged. Randomization is essential to guarantee the validity of the tests of significance which is based on the estimate of error made possible by replication. One is as important as the other.

4. We now have appropriate methods of statistical analysis, particularly the analysis of variance method by which it is possible to analyze data on the basis of the structure of the experiment itself, and by the aid of which we can resolve the total variance of the experiment into its respective components and thereby attribute the appropriate portions to the various factors included in the experimental design. By doing so we can then draw the proper conclusions for the experiment.

5. There have been developed in the last few years many types of experimental designs to meet various purposes. One of these, the randomized block design, has been illustrated here. These designs, however, have all been built up on the two principles of good design, namely, *replication* and *randomization*.

FACTORIAL DESIGN[1]

A. E. BRANDT[2]

ASSUMING that an experimenter could allow but one essential condition to vary, controlling or holding constant all other conditions, many experimenters, using biological material, fully appreciate the danger of making recommendations to the public based on the results of such experiments. Some attempts have been made to widen the basis for recommendation by laying down more complex experiments, but, in many cases, the results have not been satisfactory because the designs, though intricate and frequently very ingenious, have yielded observations that were not amenable to statistical analysis. The purpose of this paper is to show that, if properly designed, as an experiment is made more complex it becomes more efficient and more widely applicable; and to show that a design, in which two or more factors or elements each at two or more levels are investigated in all combinations in the same experiment, will attain the desired ends. Such a design is known as a factorial design.

Last year one of the research workers in the Bacteriology Department of Iowa State College asked the Statistical Laboratory to design a factorial experiment which would enable him to investigate the effects of three chemicals, at two levels each; and time, using three lengths of time, on brewer's yeast fermentation. Of one of the chemicals he wished to compare the effect of a certain amount with that of twice as much, of another he wished to compare a certain amount with one and a half times as much and of the third he wished to compare the effects of none and some. He also wished to compare the effects of allowing the fermentation to proceed for 2-, 4-, and 6-hour periods. If a treatment be defined as one length of time with one level of each of the three chemicals, 3x2 x2 x2, or 24 treatments, result.

If these treatments are assigned at random to 24 flasks, a set of 23 independent comparisons or degrees of freedom is provided. The number of independent comparisons in a set is unique, but there is practically no limit to the number of sets of comparisons. What comparison to use in an analysis follows from the design of the experiment, that is, only the set or sets which contain comparisons that will answer questions which the experiment was designed to answer should be used. In the present example, if that set is chosen in which the 23 independent comparisons are assigned to the four factors and their interactions, the analysis is as outlined in Table 1, where T represents time and A, B, and C represent the three chemicals used.

If the experimenter had run four separate experiments with 24 flasks each, attempting to control all variables except time in the first, chemical "A" in the second, chemical "B" in the third, and chemical "C" in the fourth, he would have gained no more information on the main comparisons than he received from the factorial ex-

[1]Contribution from the Statistical Laboratory, Iowa State College, Ames, Iowa. Also presented before the annual meeting of the Society held in Washington, D. C., November 20, 1936. Received for publication April 12, 1937.

[2]Assistant Professor of Mathematics and Research Assistant Professor of Statistics.

TABLE 1.—*Outline of analysis for fermentation experiment.*

Comparisons	Degrees of freedom
Main Comparisons	
T_1	1
T_2	1
A	1
B	1
C	1
First Order Interactions	
T_1xA	1
T_2xA	1
T_1xB	1
T_2xB	1
T_1xC	1
T_2xC	1
AxB	1
AxC	1
BxC	1
Second Order Interactions	
T_1xAxB	1
T_2xAxB	1
T_1xAxC	1
T_2xAxC	1
T_1xBxC	1
T_2xBxC	1
AxBxC	1
Third Order Interactions	
T_1xAxBxC	1
T_2xAxBxC	1

periment. This is not the greatest advantage of the factorial design, however, for the separate experiments would yield no information on the possible difference in the effect of different lengths of time at different levels of each of the chemicals or of different levels of one of the chemicals at different levels of a second. This differential response is known technically as interaction.

Interactions may involve two, three, or more variables or factors. Those involving two factors are known as two-way or first order interactions, those involving three factors as three-way or second order interactions, and so on. The simpler or lower order interactions, if significant, may be interpreted readily, but high order interactions, even though significant, generally do not admit of intelligible interpretation. Experience indicates that, in many cases, high order interactions are not significant, that is, one may feel reasonably certain that the apparent effects of some of the high order interactions are due principally, if not entirely, to random or sampling error and thus may serve as a basis for an estimate of the error variance against which the variances of more important or more readily interpretable comparisons may be tested.

In the outline of the analysis for the fermentation experiment, given in Table 1, there is no error term due to the fact that no actual replication of treatments was possible with the available laboratory facilities. In this example, an estimate of error, that is, an estimate of the variance, due to the errors of sampling, of a single observation, must be supplied by some of the interactions involving three or more factors. Perhaps the points so far considered can be fixed in mind best by the solution of this fermentation example. The data are given in Table 2.

TABLE 2.—*Fermentation experiment.*

Flask No.	Time in hours, T	Levels of A	Levels of F	Amounts of C	Mgs of precipitate
1..	2	Low	Low	None	140
2...	2	Low	Low	Some	95
3...	2	Low	High	None	1
4..	2	Low	High	Some	0
5.	2	High	Low	None	108
6.	2	High	Low	Some	0
7.	2	High	High	None	121
8.	2	High	High	Some	33
9.	4	Low	Low	None	151
10	4	Low	Low	Some	0
11..	4	Low	High	None	81
12..	4	Low	High	Some	2
13.	4	High	Low	None	118
14.	4	High	Low	Some	196
15.	4	High	High	None	98
16....	4	High	High	Some	186
17.	6	Low	Low	None	183
18	6	Low	Low	Some	138
19.	6	Low	High	None	169
20..	6	Low	High	Some	88
21...	6	High	Low	None	53
22...	6	High	Low	Some	0
23..	6	High	High	None	190
24..	6	High	High	Some	291

If $t_1a_2b_1c_1$ be chosen as the symbol for the milligrams of precipitate in the flask receiving the higher level of chemical A, the lower level of B and of C, and running for 2 hours; $t_3a_1b_2c_1$ for the result in the flask receiving the lower level of A, the higher level of B, the lower level of C, and running 6 hours; and so on; the comparisons given in Table 1 may be stated algebraically as follows:

$T_1 = (t_1 - t_3)(a_1 + a_2)(b_1 + b_2)(c_1 + c_2)$
$T_2 = (t_1 - 2t_2 + t_3)(a_1 + a_2)(b_1 + b_2)(c_1 + c_2)$
$A = (a_1 - a_2)(t_1 + t_2 + t_3)(b_1 + b_2)(c_1 + c_2)$
$B = (b_1 - b_2)(t_1 + t_2 + t_3)(a_1 + a_2)(c_1 + c_2)$
$C = (c_1 - c_2)(t_1 + t_2 + t_3)(a_1 + a_2)(b_1 + b_2)$
$T_1xA = (t_1 - t_3)(a_1 - a_2)(b_1 + b_2)(c_1 + c_2)$
$T_2xA = (t_1 - 2t_2 + t_3)(a_1 - a_2)(b_1 + b_2)(c_1 + c_2)$
$T_1xB = (t_1 - t_3)(b_1 - b_2)(a_1 + a_2)(c_1 + c_2)$
$T_2xB = (t_1 - 2t_2 + t_3)(b_1 - b_2)(a_1 + a_2)(c_1 + c_2)$
$T_1xC = (t_1 - t_3)(c_1 - c_2)(a_1 + a_2)(b_1 + b_2)$
$T_2xC = (t_1 - 2t_2 + t_3)(c_1 - c_2)(a_1 + a_2)(b_1 + b_2)$

$AxB = (a_1 - a_2)(b_1 - b_2)(t_1 + t_2 + t_3)(c_1 + c_2)$
$AxC = (a_1 - a_2)(c_1 - c_2)(t_1 + t_2 + t_3)(b_1 + b_2)$
$BxC = (b_1 - b_2)(c_1 - c_2)(t_1 + t_2 + t_3)(a_1 + a_2)$
$T_1xAxB = (t_1 - t_3)(a_1 - a_2)(b_1 - b_2)(c_1 + c_2)$
$T_2xAxB = (t_1 - 2t_2 + t_3)(a_1 - a_2)(b_1 - b_2)(c_1 + c_2)$
$T_1xAxC = (t_1 - t_3)(a_1 - a_2)(c_1 - c_2)(b_1 + b_2)$
$T_2xAxC = (t_1 - 2t_2 + t_3)(a_1 - a_2)(c_1 - c_2)(b_1 + b_2)$
$T_1xBxC = (t_1 - t_3)(b_1 - b_2)(c_1 - c_2)(a_1 + a_2)$
$T_2xBxC = (t_1 - 2t_2 + t_3)(b_1 - b_2)(c_1 - c_2)(a_1 + a_2)$
$AxBxC = (a_1 - a_2)(b_1 - b_2)(c_1 - c_2)(t_1 + t_2 + t_3)$
$T_1xAxBxC = (t_1 - t_3)(a_1 - a_2)(b_1 - b_2)(c_1 - c_2)$
$T_2xAxBxC = (t_1 - 2t_2 + t_3)(a_1 - a_2)(b_1 - b_2)(c_1 - c_2)$

The variance corresponding to any one of the above degrees of freedom is a fraction of the square of the product indicated on the right. Thus, for T, the variance is

$$[(a_1b_1c_1t_1 + a_1b_2c_1t_1 + a_1b_1c_2t_1 + a_1b_2c_2t_1 + a_2b_1c_1t_1 + a_2b_2c_1t_1 + a_2b_1c_2t_1 + a_2b_2c_2t_1) - (a_1b_1c_1t_3 + a_1b_2c_1t_3 + a_1b_1c_2t_3 + a_1b_2c_2t_3 + a_2b_1c_1t_3 + a_2b_2c_1t_3 + a_2b_1c_2t_3 + a_2b_2c_2t_3)]^2 \div (1^2 + 1^2)(8)$$

Substituting the observed values given in Table 2, this becomes

$$[(140 + 1 + 95 + 0 + 108 + 121 + 0 + 33) - (183 + 169 + 138 + 88 + 53 + 190 + 0 + 291)]^2 \div 16 = (498 - 1112)^2 \div 16 = 23562.25$$

For T_2, the variance is

$$[(a_1b_1c_1t_1 + a_1b_2c_1t_1 + a_1b_1c_2t_1 + a_1b_2c_2t_1 + a_2b_1c_1t_1 + a_2b_2c_1t_1 + a_2b_1c_2t_1 + a_2b_2c_2t_1) - 2(a_1b_1c_1t_2 + a_1b_2c_1t_2 + a_1b_1c_2t_2 + a_1b_2c_2t_2 + a_2b_1c_1t_2 + a_2b_2c_1t_2 + a_2b_1c_2t_2 + a_2b_2c_2t_2) + (a_1b_1c_1t_3 + a_1b_2c_1t_3 + a_1b_1c_2t_3 + a_1b_2c_2t_3 + a_2b_1c_1t_3 + a_2b_2c_1t_3 + a_2b_1c_2t_3 + a_2b_2c_2t_3)]^2 \div (1^2 + 2^2 + 1^2)(8)$$

Substituting the observed values, this becomes

$$[(140 + 1 + 95 + 0 + 108 + 121 + 0 + 33) - 2(151 + 81 + 0 + 2 + 118 + 98 + 196 + 186) + (183 + 169 + 138 + 88 + 53 + 190 + 0 + 291)]^2 \div 48 = [498 - 2(832) + 1112]^2 \div 48 = 60.75$$

For A, the variance is

$$[(a_1b_1c_1t_1 + a_1b_2c_1t_1 + a_1b_1c_2t_1 + a_1b_2c_2t_1 + a_1b_1c_1t_2 + a_1b_2c_1t_2 + a_1b_1c_2t_2 + a_1b_2c_2t_2 + a_1b_1c_1t_3 + a_1b_2c_1t_3 + a_1b_1c_2t_3 + a_1b_2c_2t_3) - (a_2b_1c_1t_1 + a_2b_2c_1t_1 + a_2b_1c_2t_1 + a_2b_2c_2t_1 + a_2b_1c_1t_2 + a_2b_2c_1t_2 + a_2b_1c_2t_2 + a_2b_2c_2t_2 + a_2b_1c_1t_3 + a_2b_2c_1t_3 + a_2b_1c_2t_3 + a_2b_2c_2t_3)]^2 \div (1^2 + 1^2)(12)$$

Substituting the observed values, this becomes

$$[(140 + 1 + 95 + 0 + 151 + 81 + 0 + 2 + 183 + 169 + 138 + 88) - (108 + 121 + 0 + 33 + 118 + 98 + 196 + 186 + 53 + 190 + 0 + 291)]^2 \div 24 = (1048 - 1394)^2 \div 24 = 4988.1667$$

To conserve space, only the last step in the calculation will be given for the other 20 degrees of freedom. These are:

$$\text{for B } \frac{(1260 - 1182)^2}{24} = 253.5$$

$$\text{for C } \frac{(1413 - 1029)^2}{-} = 6144.0$$

for T_1xA $\frac{(770 - 840)^2}{16} = 306.25$

for T_2xA $\frac{(2010 - 1264)^2}{48} = 11594.0833$

for T_1xB $\frac{(1081 - 529)^2}{16} = 19044.0$

for T_2xB $\frac{(1451 - 1823)^2}{48} = 2883.0$

for T_1xC $\frac{(887 - 723)^2}{16} = 1681.0$

for T_2xC $\frac{(1733 - 1541)^2}{48} = 768.0$

for AxB $\frac{(1626 - 816)^2}{24} = 27337.5$

for AxC $\frac{(1431 - 1011)^2}{24} = 7350.0$

for BxC $\frac{(1353 - 1089)^2}{24} = 2904.0$

for T_1xAxB $\frac{(699 - 911)^2}{16} = 2809.0$

for T_2xAxB $\frac{(1985 - 1289)^2}{48} = 10092.0$

for T_1xAxC $\frac{(967 - 643)^2}{16} = 6561.0$

for T_2xAxC $\frac{(1253 - 2021)^2}{48} = 12288.0$

for T_1xBxC $\frac{(778 - 832)^2}{16} = 182.25$

for T_2xBxC $\frac{(1646 - 1628)^2}{48} = 6.75$

for AxBxC $\frac{(1169 - 1273)^2}{24} = 450.67$

for $T_1xAxBxC$ $\frac{(912 - 698)^2}{16} = 2862.25$

for $T_2xAxBxC$ $\frac{(1492 - 1782)^2}{48} = 1752.08$

These calculations are given in such detail to provide numerical checks for those wishing to use this problem as an exercise. These variances are summarized in Table 3.

Since the 24 treatments were not replicated, there is no true error term and, as stated previously, some of the second and third order interactions will be pooled as a basis for an estimate of the error variance. It is proper to make a pooled estimate of variance only when

TABLE 3.—*Analysis of variance for fermentation experiment.*

Comparisons	Degrees of freedom	Variances	F
T_1	1	23562.2500	**5.73**
T_2	1	60 7500	
A	1	4988.1667	
B	1	253.5000	
C	1	6144 0000	
T_1xA	1	306.2500	
T_2xA	1	11594.0833	2.82
T_1xB	1	19044.0000	4.63
T_2xB	1	2883.0000	
T_1xC	1	1681 0000	
T_2xC	1	768.0000	
AxB	1	27337.5000	**6.65**
AxC	1	7350 0000	
BxC	1	2904.0000	
T_1xAxB	1	2809 0000	
T_2xAxB	1	10092 0000	
T_1xAxC	1	6561 0000	
T_2xAxC	1	12288 0000	
T_1xBxC	1	182 2500	
T_2xBxC	1	6.7500	
AxBxC	1	450.6700	
$T_1xAxBxC$	1	2862 2500	
$T_2xAxBxC$	1	1752.0800	
Total	23	145880.5000	

the mean squares are homogeneous. Chi-square may be used for this test as follows:

$$\chi^2 = \frac{n^2[S(s - \bar{s})^2]}{2(Ss)^2}$$ in which s = mean square for an individual

interaction $\bar{s} = \frac{Ss}{n}$ when n = number of interactions involved.

The table of Chi-square is entered with (n — 1) degrees of freedom. Testing the second and third order interaction mean squares for homogeneity,

$$\chi^2 = \frac{(81)\ (163,135,232)}{(2)\ (1,369,296,016)} = 4.83$$

This value is not significant so that it is proper to make a pooled estimate of the error variance, in this case, $\frac{37004}{9} = 4111.56$.

For the larger mean squares, values of F, the 5% and 1% values of which have been tabled by Snedecor,[3] are given in Table 3 The significant ones are set in bold face type. Since the first order interaction, AxB, is significant and since T_1xB approaches the 5% value, the higher order interactions containing these interactions should be examined to determine whether they might be significant as compared to a new estimate of the error variance based on the remaining degrees of freedom. Further space will not be given to this problem here.

[3]SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press. 1934.

Readers who are interested in the interpretation of the results of this fermentation experiment are referred to the thesis (not yet published) by R. W. Stone, Research Assistant in Bacteriology at the Iowa State College.

The principles illustrated by this laboratory experiment can be applied effectively to field experiments as well. Last spring an inquiry concerning a field experiment came to the Iowa State College Laboratory from a research worker in a nearby state. The experiment had been designed to test the effect of depth of plowing, rolling of seedbed just previous to planting, depth of planting, and depth of covering on the yield of potatoes. The experimenter did not ask for an opinion on his design but did ask for tests of significance which would reveal the value of the various factors in potato raising. The field layout is given in Fig. 1.

This example has been selected because the design involved is so commonly used, because this design does not provide valid tests of significance, and because, by comparatively slight modifications, designs can be made which do provide valid tests of significance. Two

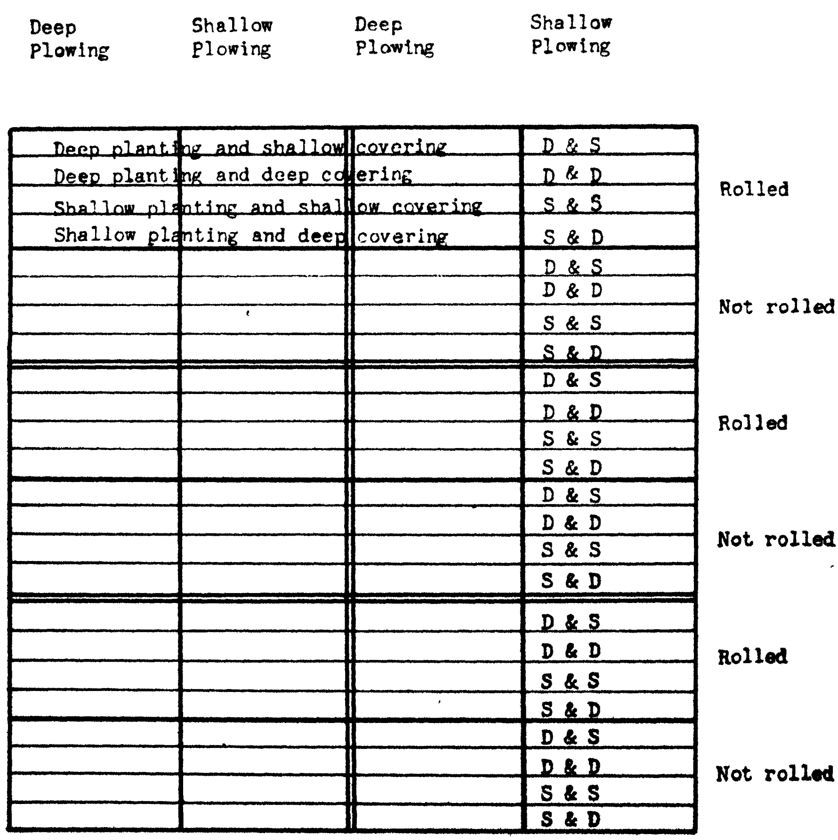

FIG. 1.—Original field layout of potato experiment.

important faults of the design as given are that the treatments run at right angles to each other and the systematic arrangement.

Tests of significance will be provided if a factorial scheme without replication is used. Since there are four variables, namely, depth of plowing (A), treatment of seedbed prior to planting (B), depth of planting (C), and depth of covering (D), and since there are two alternatives for each, 16 treatments will result. These treatments may be assigned at random to 16 of the 24 plots shown in Fig. 1. If the 15 independent comparisons which can be made among the yields of the 16 plots are assigned to the four variables and their interactions, the analysis will follow the outline given in Table 4.

TABLE 4.—*Outline of analysis for potato experiment.*

Factorial design without replication		
Comparisons	DF	
A	1	
B	1	
C	1	
D	1	
AxB	1	
AxC	1	
AxD	1	
BxC	1	
BxD	1	
CxD	1	
AxBxC	1	Error 5
AxBxD	1	
AxCxD	1	
BxCxD	1	
AxBxCxD	1	
Total	15	

This design can be criticized on two scores: first, there is no pure error term; and second, the plots are too narrow to allow the use of standard field machinery. The first criticism is distinctly valid and the second may be.

The first criticism may be met by using a factorial scheme with replication. To have two replicates of each of the 16 treatments, the field would have to be enlarged a third to provide 32 plots of the size of those in Fig. 1. The 16 treatments can be arranged at random in the first 16 plots and another random arrangement must then be used in the other 16. The outline for the analysis of such an experiment is given in Table 5.

The main effects and their interactions have been grouped under treatment in this table. This design provides a pure error term but has not overcome the narrow plots. It might be argued also that blocks of 16 plots are so large as to introduce considerable soil heterogeneity and thus increase the error term.

Since the sum of squares between blocks is subtracted from the error sum of squares, the error term will be reduced if the number of

TABLE 5.—*Outline of analysis for potato experiment.*

Factorial design with two replicates	
Comparisons	DF
Block	1
Treatments	15
Error	15
Total	31

blocks can be increased without changing other aspects of the design. Two replications of the 16 treatments may be arranged in four blocks, but in so doing one of the 15 comparisons among the 16 treatments will be identical with one of the block comparisons and thus lost, that is, one treatment comparison will be confounded with blocks. Since the research worker, in designing his experiment, may choose which of the 15 treatment degrees of freedom is to be confounded, the least important one should be selected. The highest order interaction (AxBxCxD) is almost certain to be the least important comparison and should be the one sacrificed.

If this third order interaction is stated algebraically, the method of confounding this degree of freedom is easily shown. Thus,

$$\begin{aligned} AxBxCxD &= (a_1 - a_2)(b_1 - b_2)(c_1 - c_2)(d_1 - d_2) \\ &= a_1b_1c_1d_1 - a_1b_2c_1d_1 - a_2b_1c_1d_1 + a_2b_2c_1d_1 - a_1b_1c_2d_1 + a_1b_2c_2d_1 + \\ &\quad a_2b_1c_2d_1 - a_2b_2c_2d_1 - a_1b_1c_1d_2 + a_1b_2c_1d_2 + a_2b_1c_1d_2 - a_2b_2c_1d_2 \\ &\quad + a_1b_1c_2d_2 - a_1b_2c_2d_2 - a_2b_1c_2d_2 + a_2b_2c_2d_2 \end{aligned}$$

To confound this degree of freedom, then, randomize the positive terms of the above expansion in one block and the negative terms in the other in each replication. The outline for the analysis of this experiment is given in Table 6.

TABLE 6.—*Outline of analysis for potato experiment.*

Factorial design with confounding	
Comparisons	DF
Block	3
Treatments	14
Error	14
Total	31

In this potato experiment, if the plots are too narrow for using standard field machinery, two could be combined to form a whole plot giving 16 whole plots and 32 sub-plots. If depth of plowing, treatment of seedbed, and depth of planting are designated as whole-plot treatments and depth of covering as a sub-plot treatment, eight whole-plot treatments and two sub-plot treatments result. To complete the design, arrange the eight whole plot treatments at random in each replication and then assign the two sub-plot treatments at random in each plot. The analysis of variance for a split plot experiment such as this is best made on a sub-plot basis, in which case, the sums of squares from whole-plot totals must have an extra factor 2 in

the denominator, since each is a total of two sub-plots. The outline of the analysis is given in Table 7.

TABLE 7.—*Outline of analysis (sub-plot basis) for potato experiment.*

Factorial design with split plots		
Comparisons		DF
Whole plots	Block	1
	A	1
	B	1
	C	1
	AxB	1
	AxC	1
	BxC	1
	AxBxC	1
	Error	7
Sub-plots	D	1
	AxD	1
	BxD	1
	CxD	1
	AxBxD	1
	AxCxD	1
	BxCxD	1
	AxBxCxD	1
	Error	8
Total		31

In this type of experiment the sub-plot comparisons are made with greater accuracy than are the whole-plot comparisons. As a rule, split plots should not be used if the treatment comparisons are all to be made with the same accuracy. It is a good design to use in case the whole-plot treatments cannot be applied on areas or widths as small as the sub-plots.

Factorial experiments, then, have three advantages over simple experiments They are first, efficiency—extra precision is gained from a given amount of work due to making each item available for answering a number of questions; second, comprehensiveness—more questions can be answered than if separate simple experiments are used; and third, applicability—a wider basis upon which to build inferences is provided. Another advantage which might possibly be classed as efficiency seems to be more properly labeled economy.

It is possible that at the experiment station where this potato experiment was conducted, the entomologists are conducting experiments on the control of potato bugs and other pests, the soils people are investigating chemical fertilizer mixtures, the vegetable crops people are comparing varieties, the agricultural engineers are investigating relative efficiency of types of plows or other machinery, and so on. Unless the experiment station in question is unique, many of these tests are carried out on separate fields or experimental areas and at some stations they are conducted on different farms. By means of factorial design, many experimental variants can be investigated in a single complex experiment and, though run only in duplicate, each primary question will be answered with the same precision as though the entire experiment had been devoted to that question alone.

THE EFFECT OF THREE- AND FOUR-YEAR ROTATIONS ON COTTON ROOT-ROT IN THE CENTRAL TEXAS BLACKLANDS[1]

C. H. ROGERS[2]

SINCE 1888 (1),[3] rotation of cotton with nonsusceptible crops has been recommended for the control of the cotton root-rot disease. From that time various tillage practices and 2-, 3-, and 4-year rotations (2, 3, 7, 8, 9) have been tried to determine their effect in decreasing root-rot as well as in increasing crop yields.

Scofield (7), using data from a number of different rotation combinations at the San Antonio, Texas, field station over the 8-year period 1912–19, inclusive, concluded that, "the control of root-rot is not to be found through any ordinary system of crop rotation."

Ratliffe (2), however, using the same system extended through 1932, stated that, "in these experiments 2-year rotations of cotton with nonsusceptible crops have proved of very little value in the control of root-rot, 3-year rotations appear to have been slightly more effective, while in 4-year rotations the disease has been effectively checked though not eliminated." It is noted, however, that in these rotations there was very little root-rot at the beginning of the experimental period and the various plats did not have a uniform infection.

Reynolds and Killough (3) concluded from an 11-year study of 2-, 3-, and 4-year rotations at the Temple, Texas, Substation that in every case root-rot was decreased and cotton yields increased. In a four-year rotation of cotton, cowpeas, corn, and wheat, only 4.8% of the cotton plants died from root-rot as compared with 39.7% for cotton planted continuously. Cotton yielded 101% more lint cotton in this rotation than did that grown continuously on the same land. It should be taken into consideration in this case, however, that there was considerable difference in both yields and root-rot on these different areas at the beginning and before the various rotations had completed the first cycle.

In 1927, the Temple Substation was moved to a new site on land more typical of the Blackland region. The purpose of the present paper is to give the results of root-rot studies in 3- and 4-year rotations on this station from 1928 to 1936, inclusive. In these studies the percentage root-rot, cotton yields, and the distribution and viability of sclerotia are given.

DESCRIPTION OF SCLEROTIAL STAGE

The cotton root-rot fungus, *Phymatotrichum omnivorum* (Shear) Duggar, attacks over a thousand other wild and cultivated plants besides cotton. Grains, grasses, and all other monocots, are characteristically immune. Some dicots are immune, and those tested thus far vary in degree of susceptibility. The disease is

[1]Contribution from the Division of Plant Pathology and Physiology, Texas Agricultural Experiment Station, College Station, Texas. Received for publication April 12, 1937.

[2]Plant Pathologist, Substation No. 5, Temple, Texas.

[3]Figures in parenthesis refer to "Literature Cited", p. 680.

carried over from season to season by infected roots with mycelial strands and by sclerotia (10). Sclerotia are formed in chains in the brown vegetative mycelial strands of the fungus.

In the Blacklands sclerotia are found at soil depths of 8 to 40 inches. They are from less than a millimeter to a centimeter in size and brown in color. Sclerotia not only serve as a season to season carryover, as in the case of infected roots, but are known to remain in a viable or infectious state for at least 6 years (4, 5, 11). It is of importance, therefore, to know how any cropping system or soil treatment affects these bodies.

DESCRIPTION OF CROPPING SYSTEMS

All rotations and continuous cotton areas are located on Houston black clay or Houston clay soils typical of the Blackland region. Each rotation occupies contiguous acres separated by alleys 23 feet wide running east and west and alleys 20 feet wide running north and south. The 3-year rotations occupy only parts (quarters or more) of adjoining or tiers of acres, while each crop in the 4-year rotations occupies an entire acre. Checks F-6 and D-3 each occupy half an acre, and E-1 is an entire acre. E-1 adjoins rotation No. 1, D-3 adjoins rotation No. 2, and F-6 lies nearest to rotations 3, 4, 5, and 6 but at the base of the slope. The 3-year rotations are on the opposite side of the field and about one-fourth mile from the 4-year rotations Although there are duplicate 3-year rotations and some 2-year rotations in progress on the farm, only those were used on which samples for sclerotial analysis were taken. The cropping systems studied are listed below:

No. 1. 4-year rotation of cotton, corn, sorghum, and small grain.
No. 2. Duplicate of No. 1.
No. 3. 3-year rotation of cotton, corn, and oats.
No. 4. 3-year rotation of cotton, sorghum, and oats.
No. 5. Modified 3-year rotation of cotton, cotton, and oats.
No. 6. Modified 3-year rotation of cotton, cotton, and fallow.
E-1. Continuous cotton (check).
D-3. Continuous cotton (check).
F-6. Continuous cotton (check).

The crops in each rotation are listed in sequence. In rotations 1 and 2, cotton follows small grain (wheat or oats) and corn follows cotton. In rotations 3 and 4, cotton follows oats. Although rotations 5 and 6 are identified as 3-year rotations on the Substation, they are not 3-year rotations in the sense that each crop or treatment appears one-third of the time or once in 3 years. Inasmuch as cotton appears twice in rotations 5 and 6, they are subdivided into 5a, 5b, 6a, and 6b in Tables 2 and 3. In 5a cotton follows cotton; in 5b cotton follows oats; in 6a cotton follows cotton, and in 6b cotton follows fallow. The average is given in each case in rotations 5 and 6 so that the data may be compared with figures for sclerotial distribution and viability given in Table 4. The letters in continuous cotton designations refer to the series on the Substation and the numbers to the acre in that series.

Rotations 1 and 2 are so numbered for convenient reference in this paper, while 3, 4, 5, and 6 are official station numbers. Acre E-1 and rotation 1 and part of rotation 2 are on a 1% slope. The other part of rotation 2 is on a 2 to 2½% slope. Acre D-3 is on a 3% slope. Rotations 3, 4, 5, and 6 are on a 2½ to 3% slope, and acre F-6 is on a 1% slope. All rotations occupy a soil slope and type varying between D-3 and F-6, and to a certain extent between E-1 and F-6.

Variety tests were unfortunately superimposed on both 4-year rotations since their establishment in 1928. The varieties of cotton usually numbered around 20 each year. This has little or no effect on root-rot since all varieties are entirely susceptible and in each case averaged approximately the same percentage root-rot as the entire acre. Comparison of yields, however, might be questionable. Other tests, such as fertility and date of planting, were also made on E-1 during most of the years. The non-treated plats are used for data on this acre for each year. Data for the same variety as was planted on the checks E-1 and D-3 is used in the case of these two 4-year rotations. All other rotations are planted to a single variety. Kasch was used from 1928 to 1930 and Qualla from 1932 to 1936. Lone Star (Gorham) was planted in 1931. Due to the fact that acre D-3 was on a 3% slope and was becoming eroded, it was removed from use, along with 15 additional acres, for formal experiments in 1935 and was planted to strip crop on contour.

METHODS

ROOT-ROT DATA

The percentage of plants killed by root-rot was determined by measuring with a steel tape or by mapping with a mapping machine developed by the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, Austin, Texas. This machine is mounted in wheel-barrow fashion on an ordinary bicycle wheel and has a drum approximately 8 inches in diameter on which paper for mapping is placed. A spring device in which a pencil is mounted and which is controlled from one of the handles permits the marking of linear infected areas as the machine is pushed along beside each row. Percentage infections are made from these maps. Root-rot percentage was taken as the percentage of the total lineal area planted to cotton. Stands were usually 100% and varied very little. Maps are made at intervals during the growing season, the last or final percentage being taken at or near October 1 of each year.

SCLEROTIAL STUDIES

Soil samples for sclerotial analysis were taken at 1-, 2-, and 3-foot depths with a 6-inch post-hole auger. A total of 320 post-hole samples were taken from each acre. For convenience in handling, eight post-hole samples were lumped together so that a total of 40 composite samples were taken from each acre. The eight samples for each foot interval were placed in barrels and the sclerotia separated by methods previously described (6). The viability of sclerotia was determined by germinating on moist filter paper in sterile petri dishes. In those samples with more than 100 sclerotia, only 100 were used for viability tests and calculations made therefrom.

RESULTS

ROOT-ROT STUDIES

The root-rot percentages obtained during the experimental period for the different cropping systems are given in Table 1. To obtain a basis for comparing the end results, the average for the 3-year period of 1928–30, inclusive, is used. The 6-year period of 1931–36, inclusive, shows the results after the rotations should have become effective. In the 3-year rotations the reductions or increases in root-rot are not consistent. In rotations Nos. 3 and 4 the initial and final root-rot per-

centages were much less than in the check. In rotations Nos. 5 and 6 the initial root-rot was less, but in the case of No. 5 it was more during the final period and not much difference in No. 6 for the final period. In the 4-year rotations, however, there was less than one-half the amount of root-rot in the rotation period than in the pre-rotation period; or, in other words, over 100% more root-rot was found in the initial than in the final period. The same figures apply in comparing these 4-year rotations with the average of all checks or with the nearest check.

TABLE 1.—*Average percentage of cotton killed by root-rot at end of season in various cropping systems for the periods of 1928–30 and 1931–36, inclusive.*

Cropping system		Frequency of cotton	Root-rot, %	
No.	Kind		1928–30	1931–36
1	4-year rotation	1/4 of time	71.2	29.8
2	4-year rotation	1/4 of time	45.8	19.8
E-1	Check	Continuous	80.9	66.4
D-3	Check	Continuous	46.1	58.6
F-6	Check	Continuous	65.4	67.3
E-1, D-3, and F-6	Av. of all checks	Continuous	64.1	64.1
E-1, F-6	Av. of 2 checks	Continuous	73.2	66.8
D-3, F-6	Av. of 2 checks	Continuous	55.8	63.0
3	3-year rotation	1/3 of time	31.8	39.9
4	3-year rotation	1/3 of time	56.8	57.6
5a	Mod. 3-year rotation	2/3 of time	59.8	69.2
5b	Mod. 3-year rotation	2/3 of time	29.1	78.0
Average 5a and 5b	Mod. 3-year rotation	2/3 of time	44.5	73.6
6a	Mod. 3-year rotation	2/3 of time	61.3	71.1
6b	Mod. 3-year rotation	2/3 of time	41.7	55.3
Average 6a and 6b	Mod. 3-year rotation	2/3 of time	51.6	63.2

Unfortunately, the original infection in the case of the 3-year rotations is not so definitely known as in the case of the 4-year rotations. Cotton was on the area in 1927 on which the 4-year rotations were established, but was not on the area on which the 3-year rotations were established.

The amount of root-rot on the areas occupied by the 4-year rotation No. 1 and the check area E-1 is shown in Fig. 1. The individual row data for acre B-1 in 1927 was not available, but the root-rot percentage was approximately the same as for A-1. The black lines represent the amount of root-rot per row. Rows were parallel to the adjoining railroad right-of-way in 1927, hence the diagonal effect after the standard acres were laid out. The amount of root-rot on 4-year rotation No. 2 and check acre D-3 was similar. Approximately 100% of the cotton in 1927 on all different areas was dead at the end of the season. Figs. 2, 3, 4, and 5 show the amount of root-rot at mid- and end-season on the acres in cotton in 4-year rotation No. 1 and check acre E-1 during the first 4 years following the first rotation cycle. The average root-rot percentage during this 4-year period in this particu-

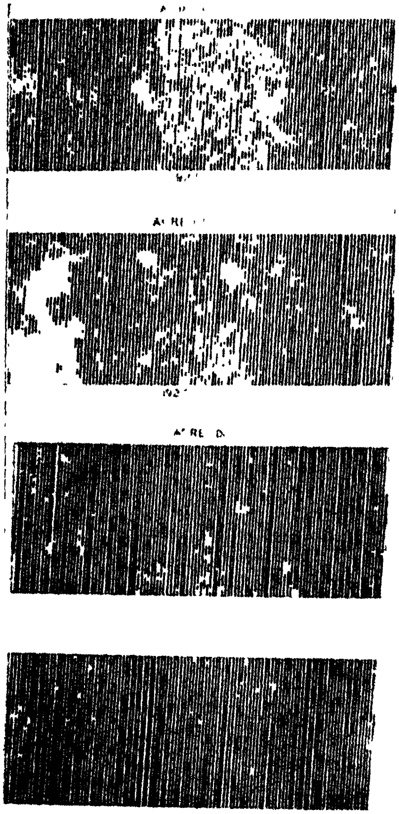

FIG. 1.—Original infection in the area occupied by 4-year rotation No. 1 and continuous cotton acre E-1.

lar rotation was 28.4 as compared with 63.5 on acre E-1, the check. The initial 3-year period (1928–30) showed an average of 71.2% root-rot in this 4-year rotation as compared with 80.9% on check E-1. The decreases in root-rot on 4-year rotation No. 2 were more outstanding than on Rotation No. 1.

COTTON YIELDS

Increases in yields of cotton from the 4-year rotations as shown in Table 2 are not in proportion to the decreases in amount of root-rot. The initial yield in both 4-year rotations was higher than the adjoining check and in No. 1 higher than the average of all checks. In rotation No. 1 the yields were increased to some extent during the final period as compared with the average of all checks. In rotation No. 2, which is on a shallower and more eroded soil than that on which No. 1 is located, the yields were higher than those of the nearest check, D-3, during the rotation period, but approximately the same as the average of all checks. In every cropping plan yields were increased in the 1931–36 period over the 1928–30 period. Although part of rotation No. 5 showed a slight decrease, there was a 7% average increase. In the 3-year rotation No. 4, consisting of cotton, sorghum, and oats, the yield was increased considerably during the final period, whereas the root-rot percentage remained approximately the same. In rotation 6b, in which cotton follows fallow, the yield was similarly increased. In this case, however, there was more root-rot during the final period than in the initial period. The average increase in all 3-year rotations, however, was somewhat higher than in the 4-year rotations. It is likely that all rotations will show a greater difference toward increased yields over continuous cotton after they are extended over a longer period of years. There is little doubt but that the 4-year rotations would show higher and more consistent yields if space permitted duplication with no introduction of added variables.

Although no data for the 2-year rotations are given in this paper, it may be stated that results were similar to those obtained from the

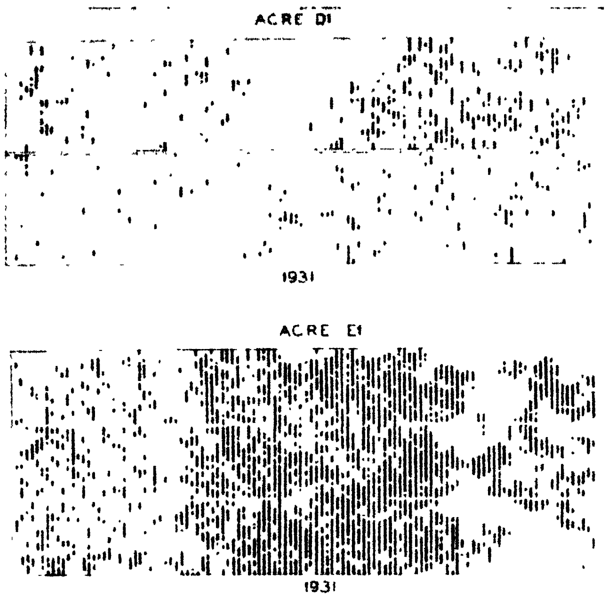

FIG. 2.—Comparison of root-rot in 4-year rotation No. 1 (acre D-1) and continuous cotton acre E-1 in 1931 after the first rotation cycle

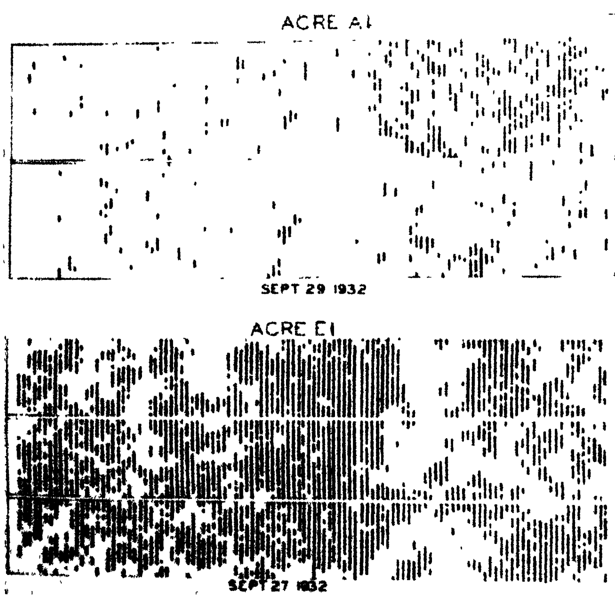

FIG. 3.—Comparison of root-rot in 4-year rotation No. 1 (acre A-1) and continuous cotton acre E-1 in 1932 after the first rotation cycle.

TABLE 2.—*Average yield of lint cotton in pounds per acre in various cropping systems for the periods 1928–30 and 1931–36, with increase during the rotation period.*

Cropping system No.	Cropping system Kind	Frequency of cotton	Yield, pounds per acre 1928–1930	Yield, pounds per acre 1931–1936	Increase during rotation period, 1931–36 Pounds	Increase during rotation period, 1931–36 %
1	4-year rotation	1/4 of time	258	304	46	17.8
2	4-year rotation	1/4 of time	209	236	27	12.9
E–1	Check	Continuous	214	270	56	26.2
D–3	Check	Continuous	155	165	10	6.4
F–6	Check	Continuous	226	237	11	4.9
E–1, D–3, and F–6	Av. of all checks	Continuous	198	224	26	13.1
E–1, F–6	Av. of 2 checks	Continuous	220	254	34	15.4
D–3, F–6	Av. of 2 checks	Continuous	191	201	10	5.2
3	3-year rotation	1/3 of time	204	225	21	10.3
4	3-year rotation	1/3 of time	211	280	69	32.7
5a	Mod. 3-year rotation	2/3 of time	185	182	−3	−1.6
5b	Mod. 3-year rotation	2/3 of time	187	215	28	15.0
Average 5a and 5b	Mod. 3-year rotation	2/3 of time	186	199	13	7.0
6a	Mod. 3-year rotation	2/3 of time	200	230	30	15.0
6b	Mod. 3-year rotation	2/3 of time	189	291	102	54.0
Average 6a and 6b	Mod. 3-year rotation	2/3 of time	194	261	67	34.5

3-year rotations in that no consistent reductions in root-rot or increases in yield were obtained. It appears that it is necessary to keep an area free of susceptible crops for a period of at least 3 years in order to reduce root-rot consistently. At the same time it will be necessary to utilize some green-manuring or other fertility practice along with such rotations to increase crop yields. The development of a desirable nonsusceptible legume would be greatly beneficial from the standpoint of forage production and for use as a green manure in the Blackland prairie region.

DATE OF KILL AS AFFECTING COTTON YIELD

If a cotton plant is killed early in the season, the yield would obviously be reduced. In Table 3, 3-year rotation 5a showed a low yield for 1935. By referring to Table 4 it will be seen that over one-half of the cotton in that rotation was killed by August 1. The same thing is observed in rotation 5b in 1936. In this case most of the cotton that ultimately died was killed by August 15. Rotation 6a had a much higher early kill for 1935 and 1936 than did 6b. The yields are correspondingly less. Rotation 5a had the highest mid-season kill for 1932, resulting in a low yield as compared with 5b. The same holds true for 6b in 1934 as compared with 6a. Similar cases are evident in almost all of the cropping systems given. Although other factors may cause

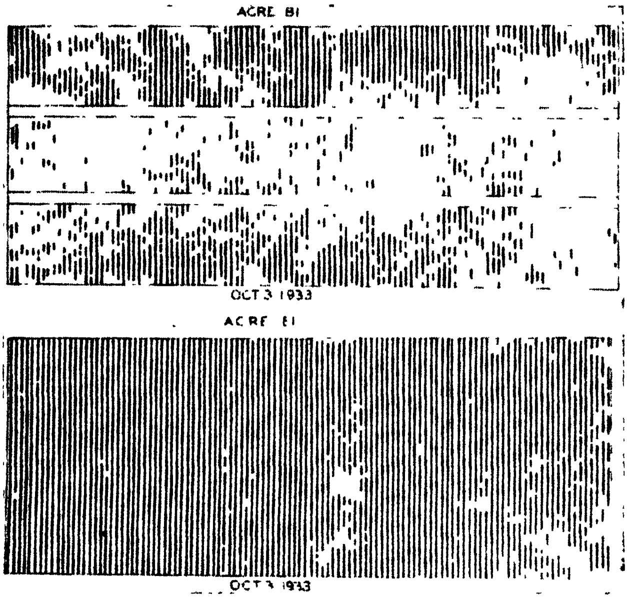

FIG. 4.—Comparison of root-rot in 4-year rotation No. 1 (acre B-1) and continuous cotton acre E-1 in 1933 after the first rotation cycle

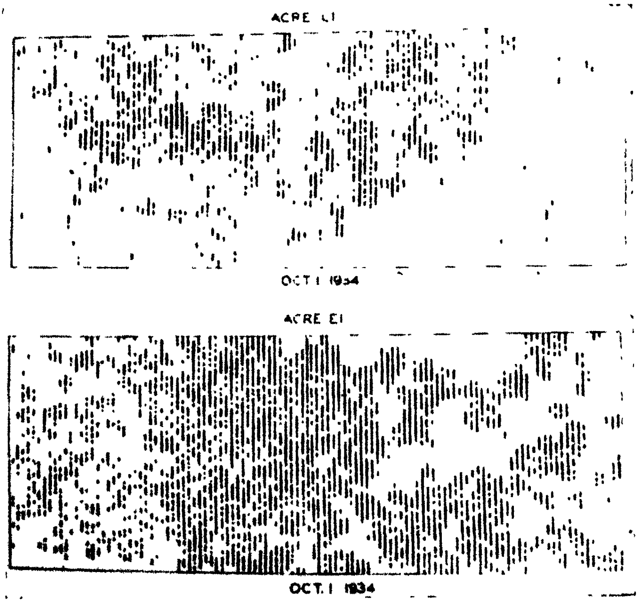

FIG. 5.—Comparison of root-rot in 4-year rotation No. 1 (acre C-1) and continuous cotton acre E-1 in 1934 after the first rotation cycle.

TABLE 3.—*Yield of lint cotton in pounds per acre by years in different cropping systems from 1928 to 1936.*

Cropping system		Frequency of cotton	Pounds lint cotton per acre								
No.	Kind		1928	1929	1930	1931	1932	1933	1934	1935	1936
1	4-year rotation	1/4 of time	338	143	293	311	281	404	285	251	292
2	4-year rotation	1/4 of time	243	140	245	272	239	336	196	120	252
E-1	Check	Continuous	246	222	174	247	208	356	269	260	282
D-3	Check	Continuous	170	227	68	176	174	164	116	193	—
F-6	Check	Continuous	254	246	178	293	320	249	264	150	148
3	3-year rotation	1/3 of time	187	160	264	213	195	376	158	216	189
4	3-year rotation	1/3 of time	182	218	233	295	242	330	230	225	356
5a	Mod. 3-year rotation	2/3 of time	154	195	205	225	180	232	190	15	247
5b	Mod. 3-year rotation	2/3 of time	152	201	207	257	341	252	180	166	92
Average 5a and 5b	Mod. 3-year rotation	2/3 of time	153	198	206	241	261	242	185	91	170
6a	Mod. 3-year rotation	2/3 of time	223	199	177	306	219	208	241	132	273
6b	Mod. 3-year rotation	2/3 of time	159	237	171	267	275	269	137	344	451
Average 6a and 6b	Mod. 3-year rotation	2/3 of time	191	218	174	287	247	239	189	238	362

TABLE 4.—*Percentage of cotton killed at mid-season and at the end of the season in different cropping systems from 1931 to 1936.*

Cropping system: No.	Cropping system: Kind	Frequency of cotton	Root-rot, %: 1931 Mid*	1931 End†	1932 Mid	1932 End	1933 Mid	1933 End	1934 Mid	1934 End	1935 Mid	1935 End	1936 Mid	1936 End
1	4-year rotation	¼ of time	—	8.0	3.0	28.0	2.9	59.4	10.9	19.0	6.1	33.2	10.6	31.0
2	4-year rotation	¼ of time	—	1.3	0	0	7.0	66.4	1.5	5.2	2.3	32.5	8.8	13.5
E-1	Check	Continuous	—	46.4	12.4	73.6	12.7	87.9	17.7	46.6	15.3	70.8	44.5	73.0
D-3	Check	Continuous	10.6	24.7	3.5	33.0	5.7	91.6	3.4	25.0	5.8	68.7	—	—
F-6	Check	Continuous	5.3	25.2	12.7	38.5	27.1	97.2	14.7	56.8	26.6	95.7	81.1	90.4
3	3-year rotation	⅓ of time	1.5	3.0	3.3	19.8	2.4	40.6	3.8	25.2	5.1	62.1	72.1	88.7
4	3-year rotation	⅓ of time	2.7	20.0	6.9	67.2	3.2	52.2	11.9	37.4	14.3	88.8	37.5	79.7
5a	Mod. 3-year rotation	⅔ of time	6.9	19.5	33.0	98.1	19.9	99.7	4.7	23.4	64.7	100.0	27.8	74.6
5b	Mod. 3-year rotation	⅔ of time	18.7	54.1	6.7	56.3	1.5	93.7	34.8	83.2	15.5	91.2	85.6	89.7
Average 5a and 5b	Mod. 3-year rotation	⅔ of time	12.8	36.8	19.9	77.2	10.7	96.7	19.8	53.3	40.1	95.6	56.7	82.2
6a	Mod. 3-year rotation	⅔ of time	8.1	32.2	14.8	86.9	3.5	84.9	22.1	54.9	13.2	94.4	54.4	73.3
6b	Mod. 3-year rotation	⅔ of time	11.2	55.0	0.6	19.7	16.1	95.0	33.8	78.5	0.7	52.5	7.1	31.2
Average 6a and 6b	Mod. 3-year rotation	⅔ of time	9.7	43.6	7.7	53.3	9.8	90.0	28.0	66.7	7.0	73.5	30.8	52.3

*Aug. 1 for 1931–35 and Aug. 15 for 1936.
†Oct. 12 for 1932 and Oct. 1 for all other years.

such variations at times, there is no doubt that a large early season kill will result in a low cotton yield. Differences in available moisture or in other environmental conditions would reflect differences in yield. These effects should, however, be similar on adjacent areas in corresponding soil types.

SCLEROTIAL STUDIES

In Table 5, the number, viability, and percentage viability of sclerotia obtained from these different rotated and continuous crop areas are given. The figures represent the average per acre in each rotation. As in the root-rot percentages, the figures for the 3-year rotations are not consistent. In the 4-year rotations the average number of viable sclerotia was less than one-third of that from the check acre E-1 or of the average of E-1 and D-3. Rotation No. 2 was more pronounced in this respect than No. 1. Sclerotia with a very low viability were obtained from the acre in 4-year rotation No. 2 that was in cotton in 1934. These sclerotia had a viability of 15% as compared with an average of 45% for the other three acres and of 38.8% for the entire rotation. The year 1934 was one of excessive drouth with very little rainfall during the growing season. The root-rot for that year in this rotation (Table 4) was only 5.2%, the lowest for any area recorded. This same acre was in cotton in 1930, another year of low root-rot kill. Samples were taken from this area in the latter part of 1936 and the first part of 1937. Since a susceptible crop appeared only twice in 8 years on this acre and since there was very little root-rot kill at those times, a very low viability count would be expected. Inasmuch as acre D-3 was in oats, a non-susceptible crop, in the winter of 1935 and the spring and winter of 1936, the sclerotial data are not comparable as a check. There appears to have been considerable reduction in the number of sclerotia on D-3 if the original stock was somewhat the same as for E-1 or F-6. After 3 years in non-susceptible crops, the number and viability of sclerotia drops off rather sharply.

TABLE 5.—*Number and viability of sclerotia under different cropping systems.*

Cropping system		Frequency of cotton	Number of sclerotia	Number of viable sclerotia	Percentage viable
No.	Kind				
1........	4-year rotation	¼ of time	4,497	2,368	52.7
2......	4-year rotation	¼ of time	4,785	1,855	38.8
E-1......	Check	Continuous	10,500	6,959	66.3
D-3	Check	Continuous	3,432	1,910	55.7
F-6......	Check	Continuous	16,371	10,955	66.9
E-1, D-3, and F-6	Av. all checks	Continuous	10,101	6,608	65.4
E-1, F-6	Av. 2 checks	Continuous	13,436	8,957	66.7
3........	3-year rotation	⅓ of time	23,460	10,798	46.0
4........	3-year rotation	⅓ of time	20,256	12,396	61.2
5........	Mod. 3-year rotation	⅔ of time	7,836	5,332	68.0
6........	Mod. 3-year rotation	⅔ of time	14,476	10,192	70.4

In Table 6 the number and viability of sclerotia in the 4-year rotation No. 1 are given for the time lapsing since each acre was planted to

cotton. In the first year following cotton the largest number of sclerotia with the highest viability is found. This is followed next by the highest number being obtained from the area in cotton at the time of sampling. These sclerotia, however, had a comparatively low viability. Two years out of cotton show the next highest figures, whereas the 3 years out of cotton show the lowest number with the lowest viability. From these data and from the standpoint of reducing the number and viability of the sclerotial stock, it would seem that an area should be kept free of susceptible crops for a period of at least 3 years

TABLE 6.—*Number and viability of sclerotia in a 4-year rotation as related to time interval since last planting of cotton.*

Time interval	Number of sclerotia	Number of viable sclerotia	Percentage viable
1 year	9,201	5,765	62.7
2 years	2,681	1,479	55.2
3 years	1,617	560	34.6
Season ending	4,488	1,665	37.1
Continuous cotton	10,500	6,959	66.3

The soil samples from each acre represent approximately 1/500 of the total soil volume in each acre to the 3-foot depth. To obtain a figure for the total number of sclerotia in an entire acre of soil, therefore, the figures for each acre should be multiplied by 500. It takes only one viable sclerotium to start an infection that might spread 20 feet or more in a single year.

SUMMARY

Three-year rotation combinations of corn, oats, sorghum, or fallow with cotton were not effective in reducing cotton root-rot caused by the fungus *Phymatotrichum omnivorum* (Shear) Duggar during the period 1928–36 in the Houston soils at the Blackland Substation, Temple, Texas.

Four-year rotations of cotton with the nonsusceptible crops corn, sorghum, and small grain (oats or wheat) showed a consistent reduction in root-rot. There was an average of over 100% more root-rot in continuous cotton than in the rotated cotton.

Small increases in lint yield were obtained from cotton in 3- and 4-year rotations. Yield increases in the 4-year rotations were not proportional to the large decreases in root-rot.

A high early or mid-season kill of cotton by root-rot results in a markedly decreased yield. Fair yields may be obtained in continuous cotton even under root-rot conditions, provided the soil is in fertile condition, and, by chance, root-rot is delayed until late season.

The number and viability of sclerotia, the primary carryover stage of the root-rot fungus, were not reduced in the 3-year rotations as compared to continuous cotton. In the 4-year rotations, however, the number and viability were not only reduced, but in the third year interval from last planting of cotton, the total number and number viable were reduced markedly.

To reduce root-rot effectively and to increase cotton yields, fields should be kept free of susceptible crops for at least a 3-year period before returning the land to cotton, and measures should be taken to increase the fertility of the soil.

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EFFECT OF AMMONIUM SULFATE ON THE RESPONSE OF SOYBEANS TO LIME AND ARTIFICIAL INOCULATION AND THE ENERGY REQUIREMENT OF SOYBEAN NODULE BACTERIA[1]

W. B. ANDREWS[2]

THE fixation of atmospheric nitrogen by nodule bacteria on legume plants has attracted the attention of many investigators. The factors affecting nitrogen fixation and the energy requirement have been subjects of investigation and thought. Allison (2)[3] made an extensive review of the literature on "carbohydrate supply as a primary factor in legume symbiosis," and one of the conclusions which he reached, calculated on the basis of the findings of Newton (6) and Reinau (7), is that, "the bacterial requirements for respiration and nitrogen fixation are probably not greater than 3 to 6% of the total carbohydrate photosynthesized under good growing conditions". On the basis of the data presented by Allison, the bacterial requirements are equal to approximately 4 to 8% of the total quantity of carbohydrate tied up in the tops and roots of the legume plant.

In experiments similar to those of Christiansen-Weniger (4), Allam (1) found in two different experiments that the soybean nodule bacteria required 26.0 and 12.6 grams of dry material (104 and 50.4 calories, respectively) to fix 1 gram of nitrogen.

The use of combined nitrogen by leguminous plants has also attracted the attention of many investigators. Recently, Thornton and Nichol (9) reviewed much of the literature on the effect of nitrates on nodule-bearing leguminous plants. They made the following critical review of data obtained from their own and similar experiments on the existing theories concerning nitrate effect:

> "The fact that the growth of the individual nodule is reduced by nitrate, renders inadequate any theory of nitrate effect such as Maze's. . .which involves a supposed action outside of the plant. On the other hand, such theories as Giobel's . . . , which attribute the effect to a change inside the nodule, seems inadequate to account for a checking of infection leading to reduced nodule numbers. The hypothesis of Allison and Ludwig . . attributing nitrate effect to reduced root growth, implies a correlation between nodule and root development, but in our experiment . . . there was no clear connection between these characters. Indeed, in the present experiment both the nodule numbers, and the volume of the bacterial tissue calculated per unit mass of root, rapidly fell off with increasing nitrate. . . ."

Recently, Umbreit and Fred (10) concluded from a series of experiments that, "under conditions which result in a balanced carbohydrate nitrogen relation in the soybean plant, free nitrogen is the preferred form of nitrogen nutrition." Umbreit and Fred used ammonium nitrate to supply the nitrogen and the soybean plants therefore re-

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[3]Figures in parenthesis refer to "Literature Cited", p. 689.

ceived the combined nitrogen in two contrasting forms, e. g., ammonia and nitrate.

The literature reviewed above shows that nitrate nitrogen is harmful to the functioning of the nodule bacteria, while Caldwell and Richardson (3) stated that, "It does appear, however, as a general conclusion, that ammonium sulphate, as such, cannot be considered specifically toxic to alsike or red clover, even when applied in relatively enormous doses, e. g., 24 grams in all per kg of dry soil."

Richardson (8) suggested that the repression of clover due to ordinary applications of sulfate of ammonia is due to the competition with the heavy growth of grass, while Umbreit and Fred (10) suggested this fact might be interpreted to mean that, "the products of symbiotic nitrogen fixation are better suited for the development of leguminous plants than are the products from combined sources."

EXPERIMENTAL

The experiment was conducted in the field on Lufkin clay soil on which soybeans had not been grown previously. The pH of the soil was 5.5. A uniform application of superphosphate was given all plats, and ammonium sulfate was applied at the rate of 0, 75, 150, 300, and 600 pounds per acre. The limed plats received 4 tons of limestone per acre. Previous work on a nearby field showed that this soil contained sufficient potash for soybeans, consequently potash was not added in the blanket treatment. The plats consisted of one row 1/400 acre in size, and they were replicated 12 times. In a few cases the data of only 10 of the plats are reported. The plat receiving no ammonium sulfate usually occurred next to the one receiving 600 pounds per acre, and as a result it produced about the same yield as the one receiving 75 pounds per acre; therefore, the data for the plat receiving no ammonium sulfate were omitted.

The soybeans were planted in May and harvested in September in the bloom stage. Approximately 10-pound samples of green soybeans were taken for moisture determinations and chemical analyses. The samples were put in burlap bags and air-dried in the greenhouse, after which they were stored in the laboratory. The analyses for nitrogen and calcium were made according to the prescribed methods of the official agricultural chemists.

Chemical analyses were made only on the soybeans receiving 75 and 600 pounds per acre of ammonium sulfate. The other samples were discarded before it was thought desirable to analyze them.

RESULTS AND DISCUSSION

The yields of soybean hay varied from 1,056 to 3,316 pounds per acre. The largest yields obtained were considerably less than the yields obtained on the best land in this vicinity, which indicates that the conditions for maximum growth had not been reached in any case.

EFFECT OF AMMONIUM SULFATE ON RESPONSE OF SOYBEANS TO ARTIFICIAL INOCULATION

Artificial inoculation (Table 1 and Fig. 1) increased the yield of soybeans 8 to 155 pounds per acre on the unlimed soil and 72 to 258 pounds per acre on the limed soil. Even though there was a small in-

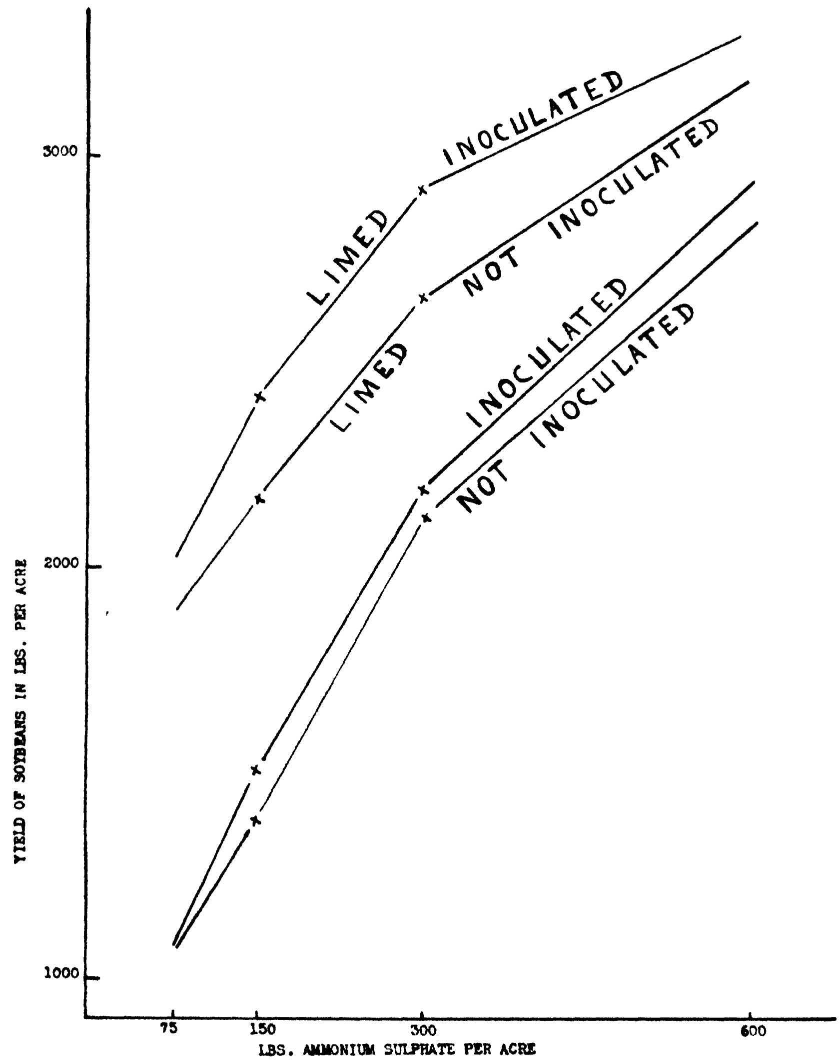

FIG. 1—The effect of ammonium sulfate on the yield of soybeans.

crease in yield in every case due to artificial inoculation, there was not a significant increase in any case, as indicated by odds calculated according to Student. The data show a slightly larger increase in yield due to artificial inoculation where the higher quantities of ammonium sulfate were used, but the differences are not significant.

On the limed soil artificial inoculation increased the nitrogen content (Table 2) of the soybeans 0.32 ± 0.085% where 600 pounds of ammonium sulfate were applied and 0.46 ± 0.055% where 75 pounds were applied. The artificial inoculation increased the percentage of

TABLE 1.—*The effect of ammonium sulfate on the yield of soybeans in pounds per acre.*

Lbs. $(NH_4)_2SO_4$ per acre				Increase	Odds*
75	150	300	600		
		Uninoculated and Unlimed			
1,056	1,375	—	—	319	553
—	1,375	2,118	—	743	9,999
—	—	2,118	2,825	707	9,999
		Uninoculated and Limed			
1,885†	2,153†	—	—	268	8
—	2,173	2,655	—	482	9,999
—	—	2,655	3,187	532	610
		Inoculated and Unlimed			
1,064	1,500	—	—	436	4,999
—	1,500	2,189	—	689	3,332
—	—	2,189	2,928	739	694
		Inoculated and Limed			
2,013†	2,433†	—	—	420	23
—	2,378	2,913	—	535	293
—	—	2,913	3,311	391	73

*Student odds
†10 plats instead of 12.

nitrogen in the soybeans receiving 75 pounds of ammonium sulfate per acre $0.14 \pm 0.102\%$ more than where 600 pounds were applied, which is not significant. On the unlimed soil artificial inoculation had no effect on the nitrogen content of the soybeans.

TABLE 2.—*The effect of ammonium sulfate on the nitrogen content of soybeans.*

Treatment	Percentage of nitrogen			
	Limed		Unlimed	
	Inoculated	Un-inoculated	Inoculated	Un-inoculated
600 lbs. $(NH_4)_2SO_4$ per acre....	1.69±0.040*	1.27±0.075	1.43±0.069	1.40±0.069
Increases for lime .	0.27±0.079	−0.02±0.102	—	—
Increases for inoculation......	0.32±0.085	—	0.03±0.098	—
75 lbs. $(NH_4)_2SO_4$ per acre...........	2.20±0.021	1.73±0.051	1.29±0.054	1.23±0.061
Increase for lime...	0.90±0.058	0.50±0.080	—	—
Increase for inoculation..........	0.46±0.055	—	0.06±0.082	—
Increase for 600 lbs. $(NH_4)_2SO_4$ over 75 lbs..........	−0.50±0.045	−0.36±0.091	0.13±0.085	0.17±0.092

*Standard error.

EFFECT OF AMMONIUM SULFATE ON RESPONSE OF SOYBEANS TO LIME

Where 75 pounds of ammonium sulfate per acre were applied, lime increased the yield of soybeans nearly 1,000 pounds per acre and where 600 pounds were applied, lime increased the yield less than 400 pounds per acre. The increases in yield due to the application of lime where the intermediate applications of sulfate of ammonia were used were intermediate. The data are reported in Table 2 and illustrated in Fig. 2.

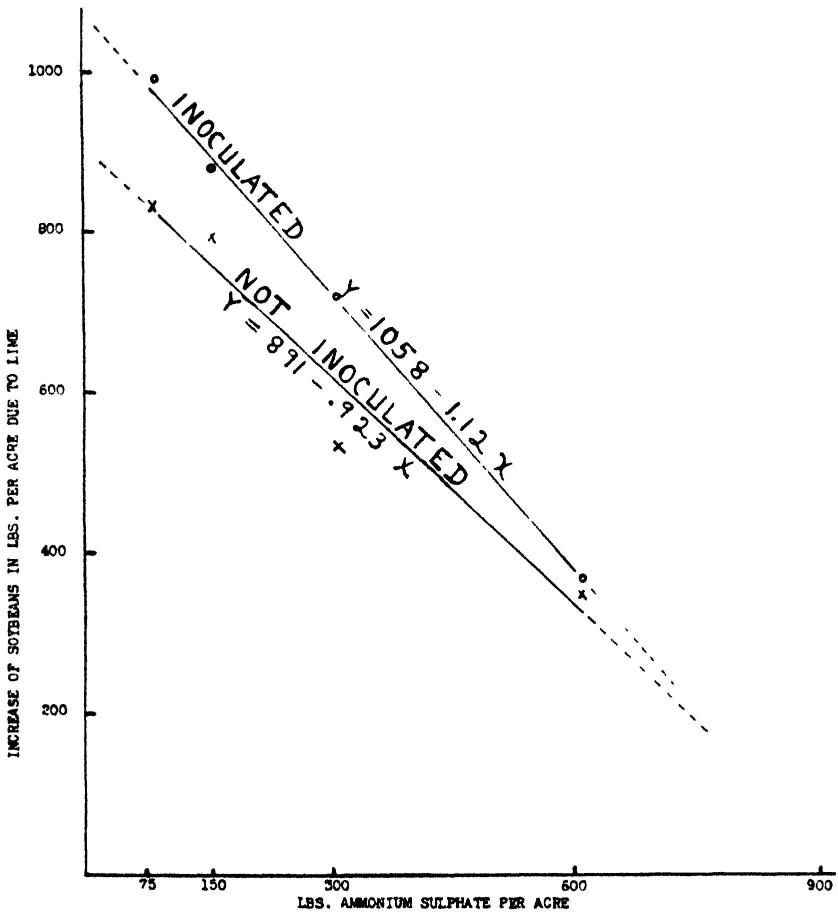

FIG. 2.—The effect of ammonium sulfate on the response of soybeans to lime.

On the inoculated series the increase in yield of soybeans per acre due to the application of lime was 1,058—1.12 times the pounds of ammonium sulfate applied. On the series receiving no artificial inoculation the increase in yield of soybeans per acre due to the application of lime was 891—0.923 times the pounds of ammonium sulfate applied. If the lines representing the data for both series are extended,

they indicate that no increase in yield would have been obtained with the use of about 900 pounds of sulfate of ammonia per acre.

These data point to the conclusion that this soil of pH 5.5 contained sufficient calcium for the nutrition of the soybean plant, that the added lime was involved in the nitrogen nutrition of the plant through the nodule bacteria, and that when sufficient nitrogen in the form of ammonium sulfate is supplied lime will have little effect on the yield of the soybeans on this soil. These data, therefore, indicate that the soybean nodule bacteria are more sensitive to a deficiency of calcium than is the soybean plant.

These data, combined with the fact that the uninoculated soybeans on the limed soil receiving 75 pounds of ammonium sulfate per acre had 0.36 ± 0.091% more nitrogen (Table 2) than those receiving 600 pounds per acre, indicate that the "uninoculated" soybeans were inoculated with a native strain of nodule bacteria even though the pH of the soil was 5.5 and soybeans had not been grown on the land previously. The data illustrated in Fig. 2 show that the soybeans inoculated with the native strain of nodule bacteria did not produce as large an increase in yield due to lime as those inoculated with artificial culture.

The data in Table 3 show that the soybeans receiving 600 pounds of ammonium sulfate per acre had practically the same calcium content as those receiving 75 pounds per acre on both the limed and the unlimed soil. However, liming the soil increased the calcium (CaO) content of the soybeans receiving 75 and 600 pounds of sulfate of ammonia per acre 0.31 ± 0 066% and 0 34 ± 0.050%, respectively.

TABLE 3.—*The effect of ammonium sulfate on the calcium content of soybeans.*

Treatment	Percentage of CaO	
	Limed	Unlimed
600 lbs $(NH_4)_2SO_4$ per acre	1.57±0.039*	1.23±0.030
Increase for lime	0.34±0.050	———
75 lbs. $(NH_4)_2SO_4$ per acre	1.57±0.034	1.26±0.057
Increase for lime	0.31±0.066	———
Increase for 600 lbs. $(NH_4)_2SO_4$ over 75 lbs	0 01±0.052	-0.03±0.064

*Standard error.

EFFECT OF AMMONIUM SULFATE ON YIELD AND ON NITROGEN CONTENT OF SOYBEANS

Increasing the ammonium sulfate (Table 1) from 75 to 150 pounds, from 150 to 300 pounds, and from 300 to 600 pounds per acre increased the yield of soybeans 319, 743, and 707 pounds per acre, respectively, on the uninoculated unlimed soybeans; 436, 689, and 739 pounds per acre, respectively, for the inoculated unlimed soybeans; 268, 482, and 532 pounds per acre, respectively, for the uninoculated limed soybeans; and 420, 535, 391 pounds per acre, respectively, on the inoculated limed soybeans. In all cases but two, the odds indicate that the data are highly significant.

The nitrogen content of the soybeans receiving 600 pounds of sulfate of ammonia per acre was higher but not significantly higher than that of soybeans receiving only 75 pounds per acre on the unlimed soil, while on the limed soil soybeans receiving 75 pounds of ammonium sulfate per acre had $0.50 \pm 0.045\%$ greater nitrogen content. On the inoculated series lime increased the nitrogen content of the soybeans receiving 600 pounds of ammonium sulfate per acre only $0.27 \pm 0.079\%$, while it increased the nitrogen content $0.90 \pm 0.058\%$ in the soybeans receiving 75 pounds of ammonium sulfate per acre. On the uninoculated series lime increased the nitrogen content $0.50 \pm 0.080\%$ where 75 pounds of ammonium sulfate were applied and no increase was obtained where 600 pounds were applied.

EFFECT OF AMMONIUM SULFATE ON NITROGEN FIXED BY SOYBEAN NODULE BACTERIA

The data in Table 4 show that artificial inoculation increased the nitrogen content of the soybeans receiving 75 pounds of ammonium sulfate 11.68 pounds and that of soybeans receiving 600 pounds of ammonium sulfate per acre 12.35 pounds. The sulfate of ammonia, therefore, had no harmful effect on nitrogen fixation by the nodule bacteria.

TABLE 4.—*Nitrogen fixation by soybeans.*

Lbs. $(NH_4)_2SO_4$ per acre	Limed		Unlimed	
	Inoculated	Uninoculated	Inoculated	Uninoculated
	Nitrogen, %			
75	2.20 ± 0.021	1.73 ± 0.051	1.29 ± 0.054	1.23 ± 0.061
600	1.69 ± 0.040	1.37 ± 0.075	1.43 ± 0.069	1.40 ± 0.069
	Hay, Pounds per Acre			
75	2,013	1,885	1,064	1,056
600	3,316	3,189	2,961	2,825
	Nitrogen in Soybeans, Pounds per Acre			
75	44.29	32.61	13.73	12.99
600	56.04	43.69	42.34	39.55
	Calculated Yields—Fixed N from $(NH_4)_2SO_4$, Pounds per Acre			
75	2,560	2,651	—	—
600	4,091	—	—	—
	Reduction in Yield Due to Nitrogen Fixation, Pounds per Acre			
75	547	766	—	—
600	775	—	—	—
	Nitrogen Fixed by Nodule Bacteria, Pounds per Acre			
75	11.68	19.62	—	—
600	12.35	—	—	—
	Pounds Hay Consumed per Pound Nitrogen Fixed			
75	46.8	39.0	—	—
600	62.7	—	—	—

ENERGY REQUIREMENT IN NITROGEN FIXATION

The data in Table 4 show that increasing the quantity of ammonium sulfate from 75 to 600 pounds per acre did not significantly affect the percentage of nitrogen of the soybeans on the unlimed soil. The soybeans receiving 75 pounds of ammonium sulfate per acre had 1.73% nitrogen; those receiving inoculation in addition to 75 pounds of ammonium sulfate per acre had 2.20% nitrogen. Based upon the fact that increasing the ammonium sulfate from 75 to 600 pounds per acre did not significantly affect the nitrogen content of the soybeans, the nitrogen content of the inoculated soybeans would have been 1.73% instead of 2.20% had the soybeans obtained an amount of nitrogen in the form of ammonium sulfate, equivalent to that which the nodule bacteria fixed.

The uninoculated soybeans contained 32.61 pounds of nitrogen, the inoculated soybeans 44.29 pounds of nitrogen. The inoculated soybeans produced 2,013 pounds per acre, and had the 11.68 (44.29–32.61) pounds of nitrogen which the nodule bacteria fixed come from sulfate of ammonia, the nitrogen content would have been 1.73% instead of 2.20% and the yield with 1.73% nitrogen would have been 2,560 pounds per acre instead of the 2,013 which was actually obtained. Therefore, the fixation of 11.68 pounds of nitrogen reduced the yield 547 (2560–2013) pounds; in other words, the fixation of 1 pound of nitrogen reduced the yield 47 pounds as compared to the yield which would have been produced if the nitrogen had been secured from sulfate of ammonia.

In a similar manner, if the soybeans of 1.69% nitrogen (inoculated, 600 pounds ammonium sulfate per acre) had obtained the additional 12.35 (56.04–43.69) pounds of nitrogen from sulfate of ammonia, the percentage of nitrogen would have been 1.37% (uninoculated, 600 pounds of ammonium sulfate per acre), and the corresponding yield would have been 4,091 pounds instead of 3,316 pounds per acre. Therefore, the fixation of 12 35 pounds of nitrogen reduced the yield 775 (4091–3316) pounds, or 63 pounds for each pound of nitrogen fixed.

Similarly, the soybeans of 1.73% nitrogen would have had 1.23% nitrogen, and the fixation of 1 pound of nitrogen reduced the yield 39 pounds below what it would have been had the additional nitrogen been obtained from ammonium sulfate. However, in the latter case the difference was due to lime and the figure is probably too low.

Fred, Baldwin, and McCoy (5) report data from which the reduction in yield due to obtaining 1 pound of nitrogen through nodule bacteria rather than as ammonium sulfate was calculated to be 38, 44, and 78 pounds.

SUMMARY

Both inoculated and uninoculated soybeans were planted on limed and unlimed Lufkin clay soil (original pH 5.5) which had received 75, 150, 300, and 600 pounds of ammonium sulfate per acre. The data show that:

1. Ammonium sulfate did not affect the response of the soybeans to artificial inoculation.

2. This soil (pH 5.5) probably contains sufficient lime to supply the need of the soybeans for growth when sufficient nitrogen is supplied as ammonium sulfate. However, lime was essential in nitrogen fixation.

3. Ammonium sulfate increased the yield of soybeans significantly when applied in large amounts, but it had little influence on their nitrogen content.

4. Ammonium sulfate did not interfere with nitrogen fixation by soybean nodule bacteria even though 600 pounds per acre were used.

5. The yield of soybeans was about 50 pounds per acre less when 1 pound of nitrogen was fixed by the nodule bacteria than where the soybeans obtained the nitrogen from sulfate of ammonia.

CONCLUSIONS

Ammonium sulfate was not harmful to soybean nodule bacteria, when up to 600 pounds per acre were used. The yield of soybeans was about 50 pounds per acre greater where ammonium sulfate was the source of nitrogen than where 1 pound of nitrogen was fixed by nodule bacteria.

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MALE STERILITY IN SORGHUM: ITS POSSIBLE UTILIZATION IN PRODUCTION OF HYBRID SEED[1]

J. C. STEPHENS[2]

INVESTIGATIONS undertaken in developing hybrid corn and the success already attained have long stimulated a desire to formulate a method for utilizing hybrid vigor in sorghum. Sorghum is largely self-pollinated, and controlled inbreeding within varieties does not materially reduce vigor. A marked increase in vigor is characteristic of many first generation hybrids among the various strains and varieties. Sorghum varieties are in this respect somewhat comparable to inbred lines of corn. An insurmountable obstacle to the utilization of this hybrid vigor, however, has been that the only known method of producing crossed seed was by the tedious process of hand emasculation and pollination.

With the discovery of a heritable male sterile in Sudan grass at Texas Substation No. 12, Chillicothe, in 1929, designated by Karper and Stephens (4)[3] as Antherless, which apparently results from a replacement of anthers by pistils, the process of transferring the character to standard varieties of sorghum was immediately begun with the hope that antherless types could be developed which would be readily pollinated by wind-blown pollen. Certain disadvantages, such as absence of lodicules to provide normal blooming, were apparent from the beginning, and it was recognized that antherless probably was not the ideal character for providing ample amounts of crossed seed for field plantings.

Another method of producing crossed seed was evolved at Chillicothe in 1932 (8), when it was found that an entire sorghum inflorescence could be emasculated in one operation by subjecting the head to a hot water treatment. This method proved very useful for certain types of crosses for breeding and genetic studies when the hybrids could be definitely distinguished from the female parent. It is disappointing, however, as a means of obtaining large quantities of crossed seed because no procedure has been perfected which assures complete emasculation without sometimes killing the entire head. Also, the cost of emasculation and of producing the hybrid seed is unavoidably high.

MALE STERILE CHARACTER

In the summer of 1935 a plant having incompletely developed anthers was observed in a plat of Texas Blackhull kafir on the Chillicothe Station. Flowers of this plant were normal in all other respects. Only one plant was found, although all plants in all the plats of this variety were examined carefully. The discovery of the plant was fortu-

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[1]Technical Series No. 393, Texas Agricultural Experiment Station. Cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station at Texas Substation No. 12, Chillicothe, Texas. Received for publication May 3, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 695.

itous because environmental sterility was very common during the 1935 season. This environmental sterility could usually be recognized, however, by the occurrence of a few normal anthers in each inflorescence which developed to the blooming stage. As many crosses as possible were made on the abnormal kafir plant during its blooming period. R. E. Karper grew the F_1 generation of four of these crosses in a greenhouse at the Texas Agricultural Experiment Station, College Station, Texas, the following winter. This made possible the growing of the F_2 generations in the field at Chillicothe in 1936 to determine whether the modification was inherited or environmental.

Anthers in flowers of all F_1 plants grown in the greenhouse and in the field were fully developed and normal in size, shape, and function. Segregation in the F_2 generation (Table 1) was clear cut and no difficulty was encountered in separating the phenotypes during periods when blooming was relatively normal. The 1936 season was exceptionally dry and hot, however, and many plants failed to head. This may account partly for the deficiency in the number of plants in recessive classes in all except one of the F_2 populations. It seems probable, however, that the sterile anther character is a simple recessive. Whenever the character appeared in any of the F_2 populations the anthers reached approximately the same stage of development, and it seems reasonable to assume that expression of the character is relatively constant for complete sterility.

TABLE 1.—*Segregation of normal and male sterile (ms) sorghum in F_2 populations grown at Chillicothe, Texas, in 1936.*

Cross	Total population	Normal	ms	% ms
ms ms* x Yel. seedling—golden†	115	92	23	20.00
ms ms* x (Bh. kafir x Sumac)	236	177	59	25.00
ms ms* x hegari . .	318	249	69	21.70
ms ms* x red leaf feterita†	249	203	46	18.47
Total . . .	918	721	197	21.46

*Texas Bh kafir
†Unreported abnormal plant color types.

The size of the anthers of male sterile plants does not exceed one-half that of normal anthers (Fig. 1). No pollen is formed in the male sterile anthers but blooming is normal otherwise, the lodicules swell, the glumes open, and the stigmas are extruded and remain exposed after the glumes close. The stigmas are thus subject to pollination by foreign pollen.

PRODUCTION OF CROSSED SEED

A brief report of the inheritance of the character and its possible usefulness in developing a method for commercial production of hybrid sorghum seed was made in a Texas Station press release in the fall of 1936 (5). Problems of using this or other male sterile types in the production of crossed seed are similar to those of the antherless character. It has not yet been determined conclusively that a high

degree of fertilization can be effected in sorghum from wind-blown pollen. In the segregating F_2 rows grown in 1936 only a few male sterile heads set seed in as many as 50% of the spikelets and most heads had only a few seeds. As previously mentioned, however, the season was exceedingly unfavorable, and the panicles of many standard self-fertile varieties were completely blasted in some plats. Anther-less panicles in segregating rows in previous seasons frequently have set seed in 75% or more of the spikelets, but only rarely have these good sets occurred in a large proportion of the antherless heads Some planting method such as closely paired rows or some form of portable mechanical air blast are possibilities for securing effective pollination.

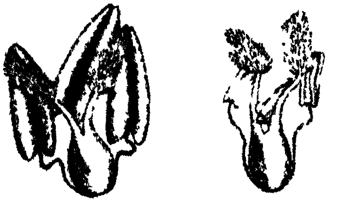

FIG. 1.—Relative size of normal and male sterile anthers. Floral organs from a segregating F_2 population extracted just previous to blooming. Outlines traced from photograph, X 6.

It may be mentioned that an average head of kafir will have more than 2,000 kernels, as compared with an average ear of corn containing 500 to 600 grains, and thus a kafir head with a 25% set of seed contains approximately as many seeds as an ear of corn. The fact that sorghum stigmas remain receptive several days after extruding (9) is a fortunate protection against short periods of weather unfavorable for the shedding and dissemination of pollen and against small differences in time of blooming.

A close estimate of the probable cost of producing crossed seed can not yet be made. The male sterile character must be maintained in a heterozygous condition Lines with 50% of male sterile plants to use as female rows in the crossing block or hybridization field could be obtained by backcrossing heterozygous plants on male sterile plants (Fig. 2). A recessive gene affecting the endosperm, seedlings, or young plants that is closely or completely linked with the gene for male sterility would greatly simplify the problem of eliminating pollen-producing segregates There is some basis in genetic studies in corn for hoping that the desired close linkage may be found in sorghum.

Singleton and Jones (7) report a male sterile in corn which is so closely linked with the factor for yellow endosperm that the fertile and sterile plants can be separated with a high degree of accuracy by separating the yellow and white seed before planting. If no useful linkage is found to permit separating normal and male sterile plants at thinning time or at any early stage, the normal plant segregates could be determined by examination of a panicle on each plant just previous to flowering. One man in a day could examine a large number of plants and remove those that would produce pollen from a population segregating for 50% each of normal and male sterile plants. This operation should be about as rapid as bagging heads, although not so rapid as that of detasseling corn.

Although observation of F_1 natural hybrids in plats and fields and the behavior of F_1 plants from artificial crosses, together with the

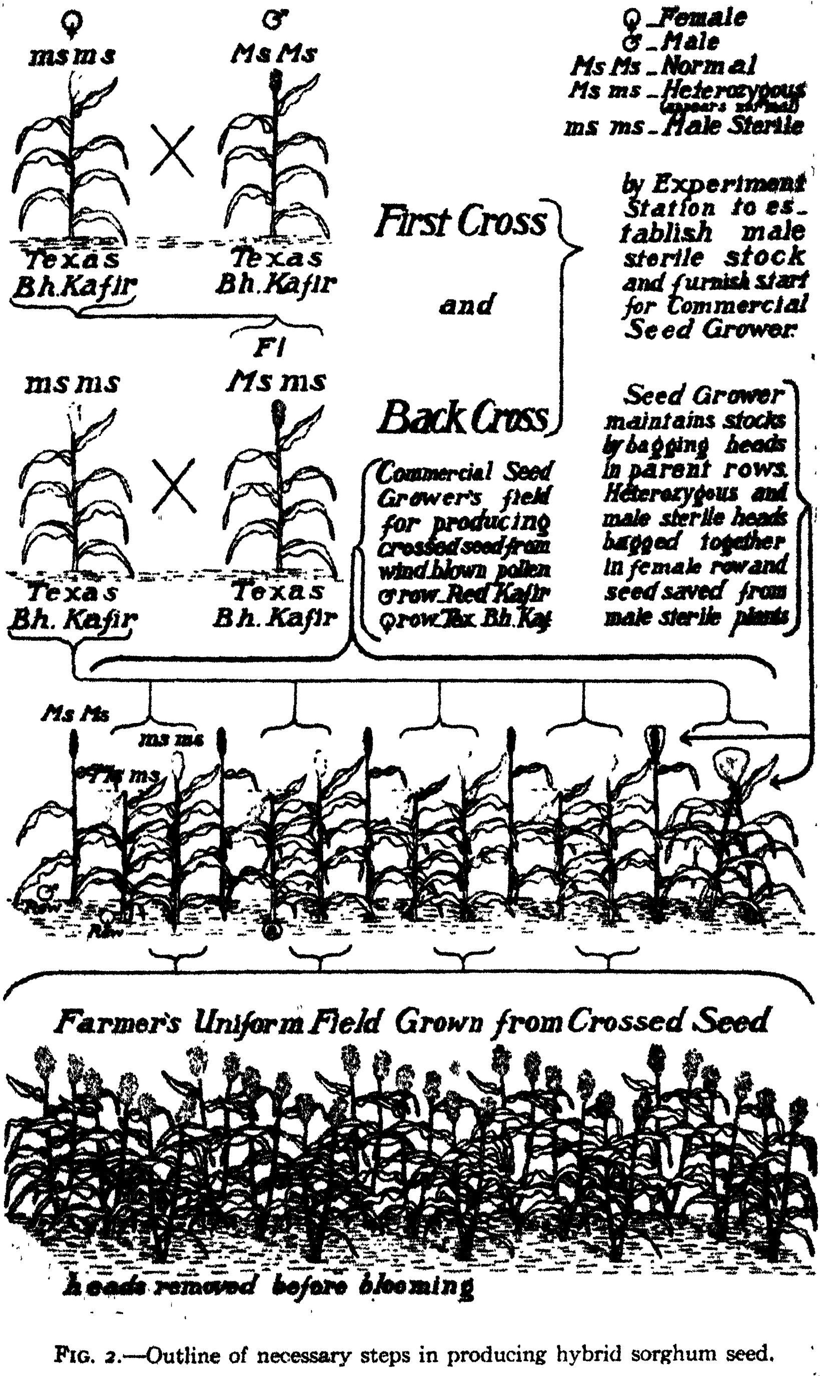

FIG. 2.—Outline of necessary steps in producing hybrid sorghum seed.

work of Conner and Karper (1), suggested that the magnitude of hybrid vigor varies greatly with different parents, no adequate information for use in selecting desirable parents has been available until recently.

In 1932, Karper and Quinby (3) compared first generation hybrids with their parents and found a large increase in production of F_1 progenies over parent varieties. The superiority of the progenies ranged from slight increases in yield when the parents were inbred lines of the same variety to more than 300% of the average yield of parental varieties, in some cases, when the parents were dissimilar varieties. Perhaps of most significance was the attention called by these writers to their results showing the increased yield of grain and forage in certain crosses without sacrificing the economically important characters, earliness and dwarfness. These latter characters are important and are characteristic of most of the varieties commonly grown in the Great Plains area.

Only a small quantity of grain sorghum seed is necessary for planting, 2 pounds of good seed to the acre usually being sufficient. Farmers could well afford to pay a substantial premium and purchase seed each year to obtain moderate increases in grain and forage production In the experiment reported by Karper and Quinby (3) the grain yield of F_1 plants of the Blackhull kafir × Red kafir cross exceeded that of the Blackhull kafir parent by over 100%. Assuming a kafir yield of 24 bushels (2), an average expectation for good cultural conditions, and a price of $1.00 per hundred, even a 50% increase in grain yield under farm conditions would result in an increased return of more than $6.00 an acre with little added expense for producing and harvesting. For this additional income a farmer could well afford to pay a dollar an acre or 50 cents a pound for the planting seed instead of the usual 4 to 10 or 12 cents. An observation of some significance made during the recent dry years is that plats from crossed seed frequently head and produce some grain during drouths in which the parental varieties fail completely.

The value of F_1 seed for forage production, whether the ultimate product is silage or fodder, probably would consist largely in the greater yields of grain which would enhance the feeding value of the forage. It is unlikely that the stover yields of the hybrids would exceed appreciably those of many of the productive late-maturing sorgos or of many varieties of sorghum introduced from tropical countries. that grow too large for convenient harvesting and handling in this country. Regardless of the possible increase in stover production, several factors contribute to a general dislike for excessive plant growth in sorghums. Heavy and unwieldy bundles, heavy exhaustion of soil moisture and plant food, and heavy stubble which is difficult to plow under and which decomposes slowly, make excessively large sorghum varieties unpopular.

High tonnage of stalks is important in sorghum grown for syrup, but sugar content, extractable juice, and flavor are other major considerations. The principal genetic factors for sweetness and juiciness have been reported (6) to be inherited independently, but apparently there are modifying factors or other causes of variation and the pres-

ent knowledge of sorghum genetics is so limited that little assumption can be made regarding the possibilities of retaining or enhancing quality and increasing production of syrup by the use of F_1 hybrids. Doubtless this problem will not be overlooked if developments in crosses within grain and forage varieties are promising.

Certified seed growers operating in Texas, and perhaps in other states, are familiar with the practice of bagging heads to maintain their foundation stocks. Maintaining male sterile stocks will be a relatively simple matter after the lines are established (Fig. 2). It will be necessary only to bag heterozygous and male sterile heads together in the back-crossed rows in the hybridization field, or to plant a small isolated field of the back-crossed stock and save seed from only the male sterile heads. Seed growers having irrigation water available could reduce the hazards from drouth at blooming and at other stages, and it would seem that facilities for commercial production of hybrid sorghum seed will be adequate whenever the experiment stations have the proper seed stocks for release.

At the present time it appears that three problems will need to be solved to render hybrid sorghum a commercial reality. Difficulty may be encountered in getting good sets of seed on male sterile heads, but it is not believed that this problem is incapable of rapid solution. The plants heterozygous for the sterility factor must be eliminated in the crossing plat and it would be a great help if some easily recognized character closely linked with the male sterile gene could be found. Finally, trials of many parental combinations will be required to find those best suited for various purposes and localities.

SUMMARY

A male sterile plant of Texas Blackhull kafir was discovered in a plat of the sorghum variety test at Texas Substation No. 12, Chillicothe, Texas, in 1935 In the F_2 generation of hybrids with this plant the progeny segregated into classes of approximately 3 normal plants to 1 male sterile plant.

Studies of hybrid vigor in sorghum, particularly those of Karper and Quinby, show that the yields from crossed seed may greatly exceed the yields of parental varieties. This male sterile character may be useful in developing a method for the commercial production of hybrid sorghum seed. A suggestive outline of the steps necessary to produce hybrid seed is presented.

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THE CHEMICAL COMPOSITION OF DROUTH-INJURED CORN PLANTS[1]

W. E. Loomis[2]

THE composition of drouth-injured corn and its relation to feeding, keeping quality, and ensilage values has been a problem of major interest in the past few years. The first effect of a midseason drouth of moderate severity is the production of a large percentage of barren or nearly barren stalks. Loomis and Burnett (7)[3] have reported that normal corn gained very little in weight during the remainder of the growing season when the ear shoots were removed at silking. Brunson and Latshaw (2) found that the stover from drouth-injured, barren stalks or from stalks bagged to prevent pollination weighed 95% as much as the stover of producing plants in adjoining plats. Thus, in these experiments, there was no yield compensation for the loss of the ear which should constitute 40% or more of the weight of the mature plant.

Sayre, Morris, and Richey (10) have found that sucrose was 51% and total sugar 36% higher in drouth-injured, barren stalks than in adjacent check stalks, and Loomis (6) has found sucrose increases of nearly 100% in defruited stalks Barr (1) found, on the other hand, that the total polysaccharides of the corn stalk were very little affected by defruiting. All of the above results were with green stalks killed in hot alcohol. Brunson and Latshaw (2) have made an extensive study of the composition of air-dried, barren and fruiting stalks. They conclude that the nitrogen-free extract of barren stalks is not significantly higher than that of fruiting stalks. Their killing method is more likely to indicate the feeding value of the corn material under farm conditions than is the rapid killing used in physiological studies. As noted above, the stalk weight of the barren plants was slightly less than that of the fruiting plants, but total nitrogen was 20 to 40% higher in the stalks and leaves of the barren plants. Brunson and Latshaw felt that this increased nitrogen percentage might greatly increase the feeding value of the drouth-injured plants.

EXPERIMENTAL RESULTS

Samples were collected in 1934 by the author at Ames and by Dr. E. R. Hensen in southern Iowa. The Ames samples were taken from a field which contained many barren stalks but which was estimated to be producing 30 bushels of corn. Normal stalks selected from this field on August 19 were in early dent and showed a yield on the basis of 8,000 plants of 50 bushels an acre. The north edge of the field was affected by moisture competition with a row of trees and no grain was produced on a strip some 100 feet wide. Plants taken from near the south edge of the affected strip were barren, stalk develop-

[1]Paper No. 456 of the journal series of the Iowa Agricultural Experiment Station; Project 545. Received for publication May 8, 1937.

[2]Associate Plant Physiologist.

[3]Figures in parenthesis refer to "Literature Cited", p. 701.

ment had been arrested in the early stages of tasselling, and the ear shoots had not emerged from the leaf sheaths. The lower third of the leaves was dry on all of the plants, and on some plants 90% or more of the leaves were dry although the stalks were green and succulent. The drier and the more succulent plants were sampled separately. Southern Iowa collections were made near Indianola in a field estimated to be making less than 5 bushels an acre. Barren but healthy stalks which had tasselled more or less normally and comparable plants showing browning and breakdown of the stalk were collected. A sample of freshly cured ensilage made from drouth-injured corn was obtained in the same area. It was dark colored and had a strong odor, but apparently was keeping satisfactorily.

All of the samples, even samples of dry leaves, were cut into boiling alcohol, the Ames samples within 20 minutes and the Indianola samples within 6 hours after collecting. Analyses for reducing sugars, sucrose, dextrin, acid hydrolysable materials, nitrates, noncolloidal organic nitrogen, and proteins were completed with methods given by Loomis and Shull (8). Duplicate samples were dried at 70° C to determine percentage of moisture in the materials as harvested. All analyses are reported as percentages of oven-dry tissue.

TISSUE YIELDS AND MOISTURE PERCENTAGES

Brunson and Latshaw (2) used plants less severely affected than those chosen here and reported no significant differences in leaf and stalk weight of barren and fruiting plants. With samples chosen to represent more severe injury, we found, as shown in Table 1, that the injured plants were only 37% of the weight of the stalks and 19% of the total weight of the producing plants.

TABLE 1.—*Acre yields of oven-dry tissue and percentage moisture in normal and severely injured corn plants.*

Tissue	Normal plants		Injured plants	
	Pounds per acre	Moisture %	Pounds per acre	Moisture %
Ears	2,760	53.8	00	—
Stalks...	1,663	78.4	640	80.6
Leaves	1,248	65.8	440	{67.8 22.0
Stover	2,911	73.1	1,080	{75.3 56.7
Plant....	5,671	63.7	1,080	{75.3 56.7

In spite of the severe injury of the affected plants, the ratio of leaves to stalk was not changed and moisture percentages in the stalks and green leaves were comparable. Much of the difficulty in handling drouth-injured corn is assigned to high moisture content. The lower figure in the brackets in the last column of Table 1 gives the moisture content of leaves or whole plants on which the leaves were well dried out. The stalks of these plants did not dry out and moisture changes

in the entire plant were limited to changes in the leaves. The 56.7% value for stover of plants with dry leaves is the same figure which would have been obtained in the normal plants if they had been picked a few days later when the leaves were still green, but the ears had dried to the 40% moisture which Robinson (9) has shown represents maturity in dent corn. The very slow drying of the stalks of injured corn makes it difficult to obtain moisture percentages at harvest below 50%, while the rapid drying of the heavy ear of normal stalks quickly reduces the average moisture percentage of the plants while the leaves are still green. It will be shown below that field drying of corn leaves results in severe losses in soluble carbohydrates; in these experiments the loss was 74%. The injured plants are thus at a decided disadvantage in that extended drying of vegetation parts is necessary to reach 50% moisture at harvest.

CARBOHYDRATES OF THE LEAF AND STALK

In common with most of the grasses (3), starch is not formed in the vegetative parts of corn, and its nearest equivalent, an amylodextrin soluble in warm water and showing a lavender color with iodine, is only a minor constituent of the plant. Sucrose is the characteristic carbohydrate of the vegetative plant and accounts for approximately half of the total carbohydrate of the stalk. The data of Table 2 show that carbohydrate accumulations above the normal level, as a result of drouth injury, were about equally distributed between dextrin and sucrose with other fractions playing a minor rôle.

TABLE 2.—*The effect of drouth injury on the carbohydrates of corn plants.*

Sample	Reducing substances %	Sucrose %	Total sugars %	Dextrin %	Soluble carbohydrates %	Acid hydrolysable %	Total carbohydrates %
			Leaves				
Normal, green	1.17	4.59	5.76	3.90	9.66	19.82	29.48
Injured, green	1.18	2.25	3.73	7.19	10.92	18.08	29.00
Injured, dry	0.44	0.36	0.80	2.02	2.82	13.88	16.70
			Stalks				
Normal	7.41	24.03	31.44	3.12	34.56	13.50	48.06
Injured, leaves green	10.32	31.70	42.02	8.70	50.72	12.77	63.49
Injured, leaves dry	7.75	24.84	32.59	5.95	38.54	14.50	53.04
S. Iowa, green	6.43	28.96	35.39	6.58	41.97	15.77	57.74
S. Iowa, rotting	1.04	1.83	2.87	6.19	9.06	26.50	35.56
			Silage				
	6.59	0.00	6.59	8.36	14.95	18.10	33.05

The data of Table 2 show carbohydrate increases of 5 to 15% in the healthy stalks of drouth-injured plants, but no increases in the total carbohydrates of leaves. We have already pointed out that the killing method used for these samples gives maximum recoveries of sucrose and other easily destroyed materials, and we consider it

significant that the sucrose percentage dropped precipitously in field dried leaves, rotting stalks, and ensilage. In these samples changes of the types which occur in farm preservation of green stalks precedes sampling, and losses as great as 25% of the dry weight and half or more of the total carbohydrate feed value of the plant were the result. The failure of the vegetative corn plant to produce starch may be considered to be largely responsible for such losses. Starch as such is not used in the respiration of the plant and it is much more resistant than sucrose to destruction by micro-organisms. Not only does the plant which produces an ear weigh 60 to 100% more than the barren, drouth-injured stalk, but most of its carbohydrate is stored in the stable forms of starch in the grain or acid hydrolysable substances in the stalk.

NITROGENOUS COMPOUNDS OF LEAF AND STALK

Brunson and Latshaw (2) stressed the higher nitrogen content of barren stalks as a factor increasing their value for feeding. In their report they use the term crude protein, apparently calculated from total nitrogen determinations. Our analyses, presented in Table 3, show that true protein in the stalks ran 25 to 30% of crude protein and that an appreciable proportion of the calculated crude protein was due to nitrate nitrogen. Animals have not been shown to synthesize amino-acids so that only the true proteins and the amino-acids of the soluble organic nitrogen should be directly available for animal assimilation. On the other hand, the bacterial flora of the digestive tract of herbivorous animals might be expected to utilize any of the nitrogen forms of corn with the possible exception of nitrates. If this use of non-amino-acid non-protein nitrogen by bacteria serves to reduce their competition with the animals for protein nitrogen, the non-protein nitrogen might be indirectly beneficial.

TABLE 3.—*Nitrogenous compounds of the leaf and stalk of corn.*

Sample	Nitrate as KNO_3 %	Nitrogen calculated as protein			
		Soluble organic %	Protein %	Total organic %	Total %
		Leaves			
Normal	0.0	1.77	9.51	11.28	11.28
Injured, green	0.03	2.78	10.48	13.26	13.29
Injured, dry	0.03	1.40	9.61	11.01	11.04
		Stalks			
Normal	0.65	2.95	1.57	4.52	5.10
Injured, leaves green	1.54	6.17	—	—	—
Injured, leaves dry	1.25	8.76	2.90	11.66	12.76
S. Iowa, green	1.42	10.06	3.69	13.75	15.00
S. Iowa, rotting	4.35	9.16	4.75	13.91	17.72
		Silage			
	2.21	8.30	5.48	13.78	15.86

The accumulation of nitrates in the injured stalks, an accumulation which was still evident in silage in the early stages of curing, is a striking feature of the data in Table 3. Nitrates are toxic in moderate doses and may be partially responsible for reported deaths of cattle fed badly injured, fresh corn stalks. Probably of more general importance is the effect of high nitrates and high soluble nitrogen combined with high sucrose on the keeping qualities of the corn, either in the shock or the silo. Drouth-injured corn heats readily in the shock and may lose much of its weight and most of its sugars during curing. Although tissues high in sucrose are difficult to preserve under any conditions, the difficulty is greatly augmented by available nitrogen to stimulate respiration and the activity of micro-organisms When silage is made of such corn the normal fermentation reactions can hardly be expected. Permitting the stover to dry in the field will, according to the analyses of Table 2, result in loss of sugars and a further narrowing of the ratio of nitrogen to carbohydrates.

SUMMARY

Severely drouth-injured corn showed the same ratio of leaves to stalks as normal plants. The injured plants weighed 37% as much as the stover of normal plants but only 19% as much as the fodder.

The failure of the corn plant to form starch in the vegetative organs makes drouth-injured or barren stalks a poor substitute for normal fruiting plants Cane sugar, which is the principal storage form of the stalk, is readily lost during curing and storage. High sugar coupled with high soluble nitrogen is favorable to heating of stover and to the formation of poor quality silage.

The rapid losses of sugars from plants left standing in the field or air dried slowly suggest that drouth-injured corn would make better feed if it could be cut while still green and dried rapidly, perhaps mowed and dried in the swath and then ensiled or handled as hay.

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COMPETITION BETWEEN COTTON VARIETIES: A REPLY[1]

B. G. Christidis[2]

IN the April 1937 issue of this Journal there was published a paper by Quinby, Killough, and Stansel, dealing with the competition between cotton varieties in adjacent rows [3] They produced considerable experimental evidence from which they drew the conclusion that, "Cotton varieties differ but little in ability to compete, that they compete the same in a favorable as in an unfavorable season, and that single-row plats can safely be used."

This conclusion is not in agreement with the one reached by the author in a previous paper[4] in which was reported the results of a cotton experiment in Greece. Quinby and his associates analysed the data given in that paper and concluded that they substantiated their findings, which are in complete disagreement with those of the author. They state (page 277 of their paper) that, "Thus the data of Christidis, if considered in this way, instead of conflicting with our own, point to the same conclusion, namely, that competition is not an important factor in cotton variety tests and that single-row plats can safely be used "

It is highly desirable that those interested in field plat technic should be made aware of the fact that this statement is completely erroneous. It appears that Quinby, *et al.*, have been the victims of a deplorable arithmetic mistake. In their Table 4 (page 277) the analysis for a-b rows is in order showing a non-significant result. In the case of b-c rows, however, the figures given in their table have nothing to do with the correct analysis of the writer's data which are given in Table 1.

Table 1.—*Analysis of b-c rows, Christidis results.*

	D. F.	S. S.	M. S.	$\log_e$ M. S.
Total	89	90.9470	——	——
Varieties	8	20.6133	2.5767	5.55122
Error	81	70.3337	.8683	4.46432
				1.08690

The z test shows in this case a most significant result since z equals .54345; whereas for $n_1 = 8$, $n_2 = 81$ and $P = 5\%$, z is only .3601 (from Fisher's tables of z by interpolation).

In order to facilitate those who would like to repeat the calculations, the 90 b-c differences for each plat are given in Table 2, as well as their sum of squares.

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[1]Contribution from The Greek Cotton Institute, Salonica, Greece. Received May 25, 1937.

[2]Director.

[3]Quinby, J. R., Killough, D. T., and Stansel, R. H. Competition between cotton varieties in adjacent rows. Jour. Amer. Soc. Agron., 29:269–279. 1937.

[4]Christidis, Basil G. Intervarietal competition in yield trials with cotton. Jour. Agr. Sci., 25:229–237. 1935.

TABLE 2.—*Differences of b-c rows for each plat, Christidis results.*

Serres	Acala	Sunshine	Delfos	Trice	Cleveland	Ingold	Car. F.	King
−0.73	0.21	−0.69	0.84	3.52	0.08	−2.72	1.00	−0.29
0.19	−0.26	0.11	0.14	−0.43	0.93	−0.96	0.93	−2.87
−0.83	0.21	−0.25	0.37	0.20	−0.49	−0.22	1.81	1.22
−3.48	−0.12	0.47	0.77	1.39	0.19	−0.44	0.38	−0.41
0.30	1.20	−0.98	0.94	1.63	−0.81	0.67	0.91	0.67
−1.58	2.00	1.15	0.59	1.11	1.54	−0.31	0.93	−0.41
−0.35	−0.98	1.02	−0.01	−0.65	0.51	−0.24	−0.44	−0.74
−0.88	0.59	0.24	−1.05	0.20	−0.99	−0.21	0.65	0.66
−0.16	0.09	0.05	−0.34	1.47	0.02	0.71	0.40	0.39
−0.52	0.91	−0.03	1.68	−0.23	0.47	−0.20	−0.67	0.02
0.49	5.21	3.04	5.33	9.52	3.74	1.38	7.01	2.96
−8.53	−1.36	−1.95	−1.40	−1.31	−2.29	−5.30	−1.11	−4.72
−8.04	3.85	1.09	3.93	8.21	1.45	−3.92	5.90	−1.76
						Total 10.71		

$\Sigma^2\ 90 = \qquad 92.2215$

$\frac{1}{10}\Sigma^2 9$ varieties $= 21.8878$

$\frac{1}{90}(\text{Total})^2 = \qquad 1.2745$

It will be noticed that this result is in close agreement with that reached by the author in his previous paper. There the differences a-b and b-c were not treated in two separate tables of analysis of variance as was done by Quinby, *et al.* Since the varieties used were randomized, there was no reason for a-b to be different from c-b, i. e., the differences a-c should not differ significantly from zero. Actually, it was found that in the analysis of the 90 a-c differences, the mean square ascribed to variety amounted to .7178, whereas that ascribed to experimental error was 1.3576. Consequently, the middle row b was compared to both outside rows a and c by using the differences ½ (a + c — 2b).

Evidently the method used by Quinby, *et al.*, differs from the author's only in detail. It should also be admitted that, it does not enable a more accurate or refined analysis of the experimental data than the one already applied. On the contrary, it is objectionable as involving an unnecessary halving of the number of observations and a decrease in the efficiency of the experiment.

A positive improvement of the treatment adopted would be the use of all the 180 possible differences of a-b and c-b in one analysis illustrated in Table 3.

It is clear that the above statistical analysis which the author has used for the last 3 years is much more significantly in favor of competition than in the case of the ½ (a + c — 2b) differences. In a paper which is to appear shortly, a full account will be given of the work and the results obtained regarding competition since the publication of the previous paper.

TABLE 3.—*Analysis of difference a-b and c-b.*

	D. F.	S. S.	M. S.	$\log_e$ M. S.
Total	179	276.9007	———	———
Varieties	8	39.7741	4.9718	1.60378
Error	171	237.1266	1.3867	.32705
				1.27673

$z = .3447$

For $n_1 = 8$, $n_2 = 172$ and $P = 5\%$ $z = .63837$

SUMMARY AND CONCLUSIONS

1. Quinby, Killough, and Stansel, using the author's data on competition, came to a contradictory conclusion and stated that, "Competition is not an important factor in cotton variety tests and that single-row plats can safely be used."

2. The above statement, in so far as the author's data are concerned, is fallacious, obviously due to an unfortunate error in calculation. The same data treated in the same way but without arithmetic mistakes point to a completely contradictory conclusion, namely, that, "Competition may cause a definite bias in estimating the comparative yielding value of cotton varieties", the conclusion reached by the author in a previous paper.

3. The slight modification introduced by Quinby, *et al.*, in the method of statistical analysis seems inadequate because it envolves an unnecessary halving of the number of observations and a decrease in the efficiency of the experiment.

NOTES

A SIMPLE METHOD OF SELF-POLLINATING COTTON FLOWERS

A NUMBER of different methods of self pollinating cotton flowers have been described. In 1912, Gilbert[1] reported a method which consisted of coiling fine copper wire in a spiral around the enlarging flower bud, making one end of the wire fast to the base of the petals and doubling the other end over the tip of the bud. The coil prevented the petals from opening and the doubled end served to retard entrance of insects. In 1913, Meade[2] described a method in which gem paper clips were placed over the unexpanded corollas. In both methods, attaching tags for identifying selfed bolls was an additional operation. In 1926, Kearney and Porter[3] described their method of bagging Egyptian cotton flowers in Arizona. The method consisted of placing small paper bags over the flower buds the day before opening. The bags were then folded and made fast with a pliable insulated wire The writer has used the paper bag method successfully by folding the bag tightly around the flower pedicel and making it fast with a paper clip. Ballard[4], in 1934, described a method in which a small paper cone was slipped over the unopened corolla and attached to the fruiting branch by a small copper wire. Another method, which is quite commonly employed by breeders, is that of snapping a small rubber band around the tip of the unopened corolla and tagging the selfed boll with a small marking tag.

Instead of attaching paper marking tags, some breeders prefer to use strings knotted around the boll pedicel. Where the tags bear any kind of an inscription, only those of the highest quality should be used; and even then, the legends are sometimes destroyed by wasps. Numerous other methods, published and unpublished, find local usage and adherents who claim certain conveniences or advantages.

The writer has employed practically all of the methods described, each of which has certain advantages; but some of these, it is felt, are largely theoretical and may be offset by laboriousness or other objections. The number of flowers to be selfed, the object of the selfing, and the amount of time or labor and materials available to do the work are, of course, the most important factors determining choice of methods.

During the season of 1935, a new method, or rather a new combination of methods, of selfing cotton flowers, was developed which seemed to be reasonably safe and was less time-consuming than other methods tried. By this method a small merchandise marking tag, strung with a 7-inch double strand of 28-gauge copper wire, is looped around the boll pedicel and the wire coiled loosely around the un-

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[1]GILBERT, W. W. A method of inbreeding cotton. Amer. Breeders Assoc., 8. 1912.

[2]MEADE, ROWLAND M. Methods of securing self-pollination in cotton. U. S. D. A. Bur. Plant Ind. Circ. 121. 1913.

[3]KEARNEY, THOMAS H., and PORTER, DOW D. Bagging cotton flowers. Jour. Heredity, 17:273–279. 1926

[4]BALLARD, W. W. A new method of self-pollinating cotton. U. S. D. A. Circ. 318. 1934.

opened corolla. The wire is coiled somewhat more tightly around the top of the corolla, as shown in Fig. 1.

This method may be used successfully in selfing flowers one or two days before anthesis. In such cases care should be taken to wrap the wire lightly around the involucel. By coiling the wire around the bud, allowance for both elongation and lateral expansion of the corolla is obtained, although not to a degree where the corolla may open. The wire may be coiled around the bractlets, which gives additional protection against bees tearing open the corolla as some times occurs with methods which keep only the top of the corolla closed, or it may be brought up directly from the boll pedicel and coiled around the tip of the corolla.

FIG. 1—Illustrating a method by which a cotton flower may be selfed, using a marking tag strung with a double strand of 28-gauge copper wire. Where bees are not troublesome, the two turns about the mid-section of the corolla may be omitted and the wire coiled around the tip only.

The most important point to observe in using tags strung with fine wire is to pass the loose end of the wire around the pedicel and under the tag so as to fasten it securely to the pedicel before bringing it sharply upward and coiling it around the corolla. The method is illustrated in Fig. 1.

Manufacturers of standard marking tags will furnish them strung with fine wire instead of string at an additional cost The advantage gained by this method is that the flowers may be selfed by a single operation, which requires little more time than the second operation of tagging a boll after the corolla has been prevented from opening. Several hundred thousand of these tags were successfully used during the season of 1936 at a number of different points throughout the Cotton Belt.—HOMER C. MCNAMARA, *Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.*

MEASURING THE IMPACT OF RAINDROPS[1]

THE erosion of soils by water is in part a function of rainfall characteristics. The beating action of falling rain drops upon the soil as well as the dispersive and cutting action of runoff water contribute to the loss of soil from unprotected lands. In studying the effect of rainfall characteristics upon erosion, it is essential to know what takes place when rain drops hit the soil. To understand thoroughly the significance of the resisting qualities of various soils and different vegetative covers to erosion, it would be exceedingly important to be able to measure the impact with which rain strikes the

FIG. 1.—Apparatus for measuring the impact of raindrops. A, analytical balance beam; B, aluminum plate receiving impact; C, spring driving mechanism; D, clock regulating mechanism; E, spiral spring regulating deflection; F, metal cover.

[1]The authors wish to express their appreciation for the suggestions offered by C. M. Woodruff, D. D. Smith, and D. M. Whitt of the Bethany Soil Conservation Experiment Station, during certain phases of this study.

soil under varying rainfall intensities. It would also be extremely valuable to compare the impact of artificial and natural rains.

Before the impact of a falling drop of water can be evaluated, it is necessary to know its velocity of fall. An experimental study of the rate of fall of drops of water of different sizes from varying heights showed that their acceleration varied approximately inversely as the square root of the time. During the first second the acceleration was fairly rapid. Acceleration then decreased markedly and became negligible a few seconds after the drop had started falling. Therefore, after a few seconds, the drop falls almost with a constant velocity. This approximately constant velocity was obtained after the drop had fallen from 7 to 10 feet. These results indicate that the impact of rain drops per unit area at a given time will be determined by the number and size of the drops plus any increase in velocity due to the driving force of the wind.

An apparatus has been constructed to measure and automatically record the impact of falling drops of water (Fig. 1). It consists of an analytical balance beam mounted on a steel point bearing (agate would be superior). By means of a stem screwed into the top of one end of the beam, a small aluminum plate is mounted which receives the impact. A recording pen is attached to the other end of the beam. This pen is a capillary glass tube which dips into an ink well. The recording end is turned horizontally, drawn to a point, and inclined slightly downward to facilitate the steady flow of the ink.

The deflection of the pen resulting from the impact of rain drops on the pan is recorded on a chart on a drum which is driven by a spring and regulated by a clock. The length of the pen arm of the beam is about 3½ times that if the plate arm which magnifies the deflection by that ratio. The magnitude of the deflection for a given impact is controlled by the elongation of a small spiral spring attached to the long arm of the beam. The apparatus was calibrated by determining the deflection resulting from the impact of drops of water of known mass and velocity.

The entire apparatus is enclosed in a metal case with an opening in the top to accommodate the pan. The pan rests about 1 cm below the top of the case to prevent deflections due to wind movements. Complete details of the applicability of this apparatus will appear in a forthcoming publication.—J. H. NEAL and L. D. BAVER, *Department of Soils, University of Missouri, Columbia, Mo.*

MONOECIOUS BUFFALO GRASS, *BUCHLOE DACTYLOIDES*[1]

A NURSERY plat of 429 buffalo grass plants started as seedlings in the greenhouse in March 1936 at Manhattan, Kansas, then transplanted to the field in May were examined in May, 1937, after flowering was well under way. This examination disclosed 25 plants, or 5.8% of the total, that were monoecious and 2 more in which both staminate and pistillate inflorescences were found but could not definitely be shown to occur on the same stolon. The remaining 402

[1]Contribution No. 268, Department of Agronomy, Kansas Agricultural Experiment Station.

plants are about equally divided into pure staminate and pure pistillate plants.

Plank[2] reports finding hundreds of seedling plants in soil newly moved by a freshet and that all of these seedlings were monoecious. Hitchcock[3] describes a monoecious plant of buffalo grass, but in no case did he find the two kinds of inflorescences growing from the same node, and he was unable to determine whether the two kinds of flowers were borne upon independent stolons. Schaffner[4], from observations in Clay County, Kansas, found no monoecious plants and states that he finds no evidence whatever that monoecious forms exist.

The plants described here (Fig. 1) are without doubt monoecious, for in each of the 25 both pistillate and staminate inflorescences were found on the *same stolon* and in a number of cases from the *same node*. The seed from which these plants were grown came from two pastures at Hays, Kansas, and one in Oklahoma. Monoecious plants are found in about the same proportions in each lot.

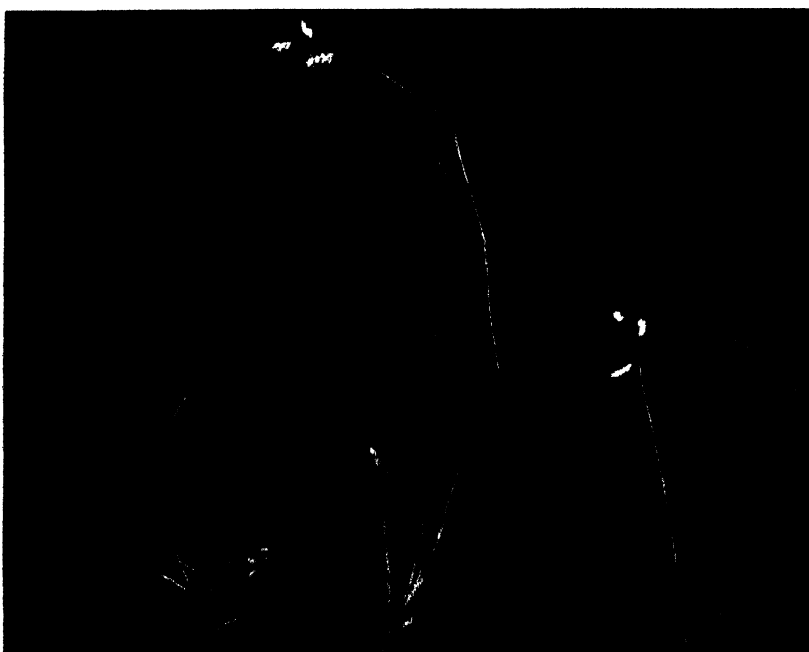

FIG. 1.—Buffalo grass, *Buchloe dactyloides*. 1, pistillate plant; 2, monoecious plant; 3, staminate plant.

These monoecious plants have been removed to an area where there are no dioecious plants nearby so that this character may be studied.—KLING ANDERSON and A. E. ALDOUS, *Department of Agronomy, Kansas State College, Manhattan, Kansas.*

[2]PLANK, E. N. *Buchloe dactyloides*, Englun., not a dioecious grass. Bul. Torrey Club, 19:303–306. 1892.

[3]HITCHCOCK, A. S. Note on buffalo grass. Bot. Gaz., 20:464. 1895.

[4]SCHAFFNER, JOHN H. Dioecious nature of buffalo grass. Bul. Torrey Club, 47:119–124. 1920.

BOOK REVIEW

1936 PROCEEDINGS OF THE SOIL SCIENCE SOCIETY OF AMERICA

Ann Arbor, Mich.; Edwards Bros. Lithoprinted from typewritten pages; cloth bound. VIII + 526 pages, illus. 1937. $5.

THIS volume contains the first proceedings of the Soil Science Society of America, established November 1936 by the merging of the American Soil Survey Association and the Soils Section of the American Society of Agronomy. The 86 papers given at the 1936 meeting are published in this volume, some in complete form, others as author abstracts

The first 32 pages are taken up by the three papers given at the general program. They are followed by the papers of the six sections as presented at their respective programs, namely, I, Soil Physics, 88 pages; II, Soil Chemistry, 74 pages; III, Soil Microbiology, 30 pages; IV, Soil Fertility, 74 pages; V, Soil Genesis, Morphology, and Cartography, 57 pages; VI, Soil Technology, 92 pages; and V and VI, Joint Symposium on Soil Science and Land Use, 52 pages.

The final 20 pages are taken up by reports of business, lists of officers, the constitution of the Soil Science Society, and an author index of the volume. (H. J. C.)

AGRONOMIC AFFAIRS

MEETING OF WESTERN BRANCH

THE twenty-first annual meeting of the Western Branch of the Society was held at the Montana State College at Bozeman July 19 to 21, inclusive, with forty-nine agronomists from ten states and the U. S. Dept. of Agriculture in attendance. About twenty papers were presented in addition to various discussion periods. An inspection was made of the agronomy field plats and the cereal and forage nurseries at the Montana State College.

Officers of the Branch for 1937 were Dr. B. B. Bayles of the U. S. Dept. of Agriculture, *President*, and Director Clyde McKee of the Montana Agricultural Experiment Station, *Secretary*. The newly elected officers for 1938 are Dr. K. H. Klages of the University of Idaho, *President*, and Prof. Ian A. Briggs of the University of Arizona, *Secretary*. The group voted to hold the 1938 meeting at the University of Arizona.

NEWS ITEMS

THE DIVISION OF COOPERATIVE EXTENSION of the U. S. Dept. of Agriculture announces that the prices for film strips issued by the Department will be the same for the fiscal year of 1937-38 as for the past year. A list of available film strips and instructions on how to purchase them may be obtained by writing to the Division of Cooperative Extension.

DR. A. L. PATRICK has been made director of surveys and DR. JOHN P. JONES regional conservator of the Soil Conservation Service for the Northeast Region. As chief of the survey division, Dr. Patrick will direct the work of the Soil Conservation Service in connection with flood control planning as well as the regular erosion and land use studies needed as a basis for soil conservation in 170 demonstration areas in 43 states.

SIR CHARLES SAUNDERS, first Dominion Cerealist and creator of Marquis wheat, died at his home in Toronto on July 25 at the age of 70. Sir Charles retired from his position as Dominion Cerealist in 1925, and in 1934 was knighted by the King in recognition of his services to Canada and the Empire.

THE FULL PAPERS read at the fourth International Grassland Congress at Aberystwyth in July, together with the accompanying discussions, will be published in a report of the Congress to be issued in the fall. A volume of abstracts covering the 75 papers presented at the Congress is now available. The subjects dealt with range from ecology of grassland and management of pastures to plant breeding and seed production, fertilizers, and questions connected with animal nutrition. The Abstracts and complete Proceedings will be available for £ 2 sterling; the Abstract volume alone for 5/-. Orders should be placed with the Joint Secretaries, Fourth International Grassland Congress, Aberystwyth, Great Britain.

P. H. STEWART, Extension Agronomist of the University of Nebraska, College of Agriculture, since 1919 took leave of absence April 19 to work with the Federal Land Bank of Omaha as Manager of the Farm Service Division involving the operation of farm properties of the bank.

DR. CARLETON R. BALL, Extension Service, U. S. Dept. of Agriculture, has on hand varying numbers of most of his numerous publications on agronomic topics which he will be glad to send to interested persons as long as the supply lasts. The papers cover general agronomic topics, agronomic terminology and writing, relation of agronomy and botany, cooperation, forage crops, sorghums, and wheat.

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THE ERROR IN GRAIN YIELD ATTENDING MISSPACED WHEAT NURSERY ROWS AND THE EXTENT OF THE MISSPACING EFFECT[1]

G. A. WIEBE[2]

IN America it is a common practice to test the yielding ability of small grains in what is commonly called a nursery row. These rows usually are 12 inches apart and their length varies from 15 to 20 feet, depending on the kind of grain grown and the area of land available for testing. Usually several contiguous rows are planted to the same variety and this unit is called a nursery plot. One, three, four, and five rows per plot are sizes commonly used.

This paper deals with errors in grain yield resulting from misspaced rows, i.e., those not exactly 12 inches apart. For example, the following series of 10 spacings of 12, 12, 13, 12, 12, 12, 11, 11, 12, and 12 inches between 11 contiguous rows might occur in an experiment. There are two rows having a 12-inch space on one side and a 13-inch space on the other, two rows having a 12-inch space on one side and 11 on the other, and one row having an 11-inch space on each side. In a soil of uniform depth, therefore, the area over which the roots may feed is not the same for the misspaced rows as for those which have a 12-inch space on each side.

MATERIAL

The data for this study became available in the course of an experiment with Federation wheat conducted at the Aberdeen Substation, Aberdeen, Idaho,[3] which was sown with an ordinary horse-drawn grain drill. The alternate holes of the drill were plugged so that eight rows 12 inches apart were sown on each trip across the field. After the wheat emerged, the rows were cut into series making 1,500 rows 15 feet long. At seeding time and later it became apparent that where two drill strips adjoined, the space between them was not always 12 inches.

The stippled area in Fig. 1 shows in an exaggerated way how this space between drill strips varied. The space between drilled strips changed very little within a

[1]Contribution from the Division of Cereal Crops and Diseases. Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication May 10, 1937.

[2]Agronomist.

[3]WIEBE, G. A. Variation and correlation in grain yield among 1,500 wheat nursery plots. Jour. Agr. Res., 50: 331–357. 1935.

15-foot length of row. Measurements between drill strips were taken at three points on each of 168 adjacent 15-foot lengths of row. The arrows in Fig. 1 indicate the points on each row at which these were taken. The space between rows ranged from 7 to 17 inches.

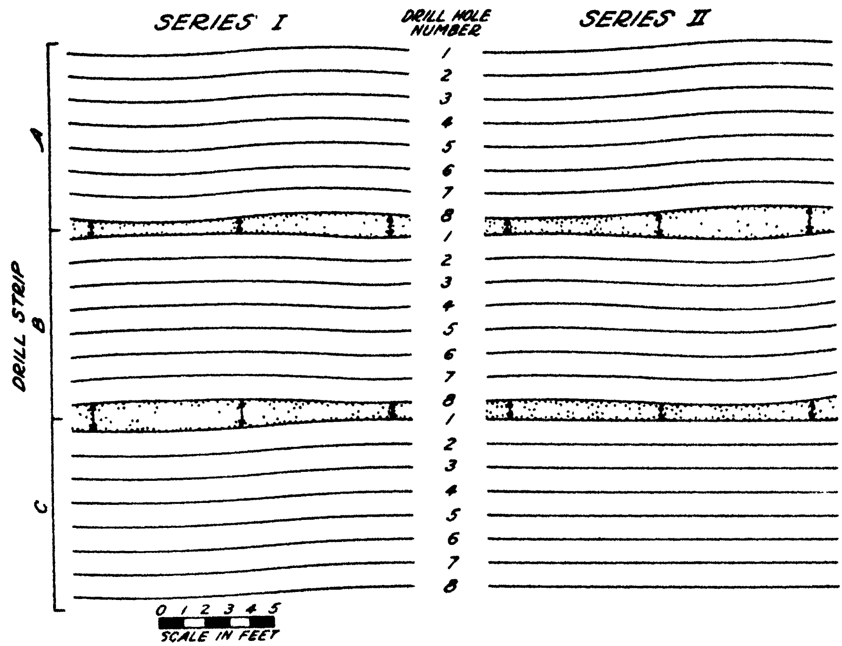

FIG. 1.—Field plan showing variation in the space between drill strips (stippled area). The arrows indicate places at which measurements were taken. (The variations are exaggerated for purposes of illustration and only a small part of the field is shown.)

RESULTS OBTAINED

In order to secure an estimate of the error in yield due to mis-spaced rows, the regression of yield per row on space between drill strips was calculated. However, before this was done, it seemed desirable to attempt some statistical control of the differences in productivity over the area. Obviously the best measure of the regression would be one obtained on a soil whose productivity did not change from place to place. In order to eliminate a large part of this influence from the experiment, a moving average was calculated and used as a measure of the productivity of the soils at the points studied. This average was centered at a point between the drill strips. In series I, for example, the first moving average used was the average yield of the rows from drill rows 2, 3, 4, 5, 6, and 7 in drill strips A and B. The second moving average is the average yield of the rows from drill holes 2, 3, 4, 5, 6, and 7 in drill strips B and C, and likewise throughout the experiment. The yields of the rows from drill rows 1 and 8 were not used in computing the moving average because they were affected by the varying space between drill strips. By using the mov-

ing average as a measure of the productivity, it was possible then to calculate a partial regression of yield on space with productivity held constant. By this method the average regression of the yields of rows 1 and 8 on space between drill strips, with productivity constant, was found to be 21.5 grams (Table 1). This means that with every inch of variation in the space between rows there was an error in grain yield of 21.5 grams. This was equivalent to 3.8% of the mean yield of these rows.

TABLE 1.—*Simple and partial correlation coefficients and partial regression coefficients of the variables yield per row, space between drill strips, and productivity (moving average of yield) for drill rows 1 and 8 adjacent to space between drill strips and drill rows 2 and 7 once removed from space between drill strips.*

Item	Drill holes	
	1 and 8	2 and 7
Simple correlations:		
Yield per row and space between drill strip	0.434*	0.071
Yield per row and productivity (moving average of yield)	0.830*	0.918*
Space between drill strip and productivity (moving average of yield)	0.052	0.052
Partial correlations:		
Yield per row and space between drill strip with productivity (moving average of yield) held constant .	0.700*	0.058
Partial regressions:		
Yield per row on space between drill strip with productivity (moving average of yield) held constant. . .	21.52*	1.27

N = 168 in all cases

*Significant values.

The average regression of the yields of rows 2 and 7 on space between drill strips, with productivity constant, also was calculated to determine if the effect of misspacing extended to the second row. The regression found (1.27 grams) does not differ significantly from zero. This indicates that the yields of rows once removed from the varying space were not influenced significantly by the varying space. The data also may be regarded as contributory evidence supporting the contention that the center row of a three-row plot is free from competition with adjacent varieties.

The relation between yield and space over the range studied was found to be linear. Where the gain and loss in space for a row are compensating, e.g., an 11-inch space on one side and a 13-inch space on the other, or 10 and 14 inches, the yield would be the same as if the space had been 12 inches on both sides because of the linear relationship of space and yield.

CONCLUSIONS

It was found that the error in grain yield per row resulting from misspaced nursery rows amounted to 3.8% per inch for each inch the rows were misspaced.

The regression of yield on space is linear over the range (7 to 17 inches) of spacings studied.

The yields of rows once removed from the varying space were not affected significantly.

Where the gain and loss of space on opposite sides of a row are equal, no error in yield is introduced.

A MECHANICAL APPARATUS FOR THE RAPID, HIGH-TEMPERATURE MICROBIAL DECOMPOSITION OF FIBROUS, CELLULOSIC MATERIALS IN THE PREPARATION OF COMPOSTS FOR MUSHROOM CULTURES[1]

B. B. STOLLER, F. B. SMITH, and P. E. BROWN[2]

THE method used at present to obtain a partial decomposition of horse manure in the preparation of composts for mushroom culture is to make a compost heap about 3 to 6 feet high and any convenient length and width. The compost heap is turned every 5 to 10 days with a pitch fork to mix and sufficient water is added to maintain a moisture content of about 60 to 70%. Some of the larger growers use an elevator similar to those used in loading coal to mix the compost. Several such turnings and mixings are made over a period of 4 to 7 weeks, the length of time being longer in the case of fresh manure or manure containing a high percentage of strawy bedding. At the end of this "composting" the manure is made up into mushroom beds. The amount of decomposition in the compost as measured by the loss in dry weight is 25 to 40%, according to Waksman and coworkers (4, 5, 6).[3]

Lambert and Davis (2) have recently made a study of the aeration, temperature, acidity, and moisture in the mushroom compost heaps. They sampled the air in various parts of the compost heap and found that more than half of the heap was under anaerobic conditions (20 to 30% of carbon dioxide and no oxygen), and stated that it would take two or three times as long to decompose this lower anaerobic part as the outer aerated portions were it not for the thorough mixing obtained during the turning process. They concluded that the aerated condition in the compost heap is preferable to anaerobic conditions provided it can be maintained without excessive heating or drying out of the manure.

Under present conditions of making mushroom composts some of the manure becomes too wet and some too dry, some too acid or too alkaline, and some too "green" or decomposed too far. However, the turning and mixing of this material over a period of several weeks diminishes extremes of this kind; yet, this hand-turning of the compost to obtain a homogeneous material requires much time and the final product is never uniform in composition.

One of the greatest menaces to mushroom cultivation is insects which may reduce the yield to the point where the business is unprofitable. Insects are most commonly introduced in the mushroom house with composts which did not heat enough in certain portions to kill them. If the manure could be prepared at a uniformly high temperature and the final product transferred perhaps by an elevator

[1]Journal paper No. J459 of the Iowa Agricultural Experiment Station. Project No. 444. Received for publication May 17, 1937.

[2]Research Fellow in Botany, Research Associate Professor of Soils, and Head of Department of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 723.

or a blower, insect and fungous pests might be largely, if not entirely, eliminated.

The purpose of this work was to construct a mechanical apparatus in which the aeration, moisture, temperature, and acidity can be controlled in order to obtain a rapid, high-temperature decomposition of horse manure and artificial manure in the production of composts for mushroom culture.

APPARATUS AND METHODS

The principle underlying the construction of this apparatus was to devise means for maintaining a constant moisture content, conserving the heat generated by the thermophilic fermentation, maintaining good aeration without excessive drying or cooling effects, and revolving the fermenting mass so as to obtain the proper moisture, temperature, and aeration in every part of the compost. This apparatus would also serve as a convenient tank for turning, mixing, and watering the compost so as to obtain a homogeneous product

The apparatus used in these experiments, as shown in Fig. 1, consisted of a butter churn from which all of the rollers were removed, but the two baffles protruding 3 inches from the sides were allowed

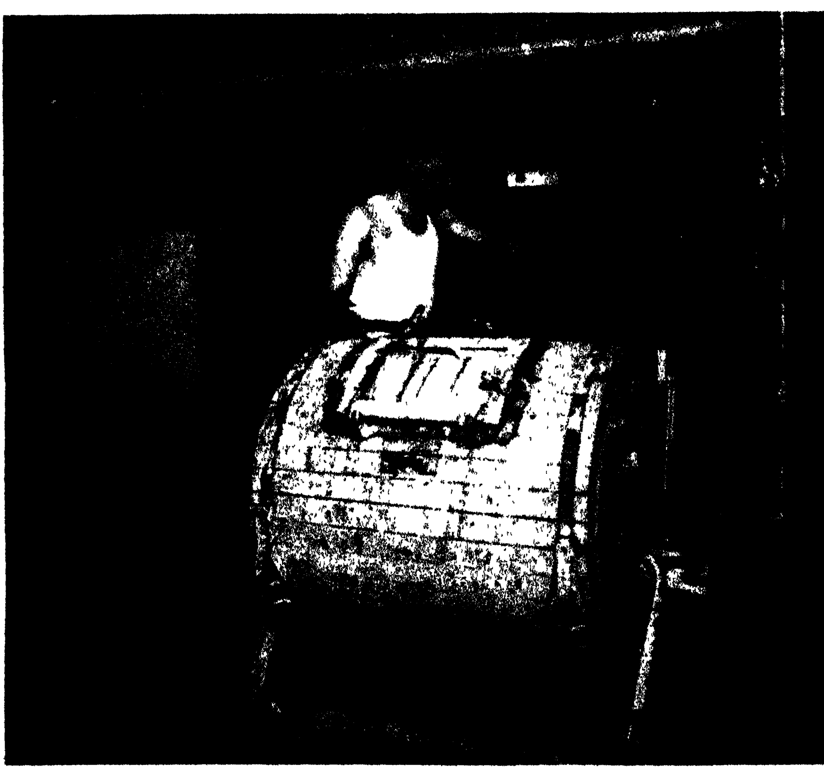

FIG. 1.—Apparatus for rapid decomposition of cellulosic materials.

to remain. A 1-inch pipe with ⅛ inch holes about 2 inches apart was inserted through the central part. At one end the pipe was connected to an air line, and at the other end it was sealed, a piece of ¼-inch copper tubing passing through the seal so as to permit of the sampling of gases in the cylinder while it revolved. A water connection was also made along with the air inlet. The churn was geared down to make about one revolution in 8 minutes.

The quantity and rate of air entering the cylinder was measured at first with a wet-test gas meter but later with a calibrated flow meter. The carbon dioxide and the oxygen determinations were made with a Williams modification of the Orsat apparatus. The moisture determinations were made on 100-gram samples by drying in an electric oven at 105° C. The ash analysis was made in an electric muffle furnace at 700° C.

Fifty-five and four-tenths kilograms of fresh horse manure containing 67% moisture were placed in the churn and the churn started immediately. The air sample for the carbon dioxide and oxygen determinations was taken 1 minute after the air supply was cut off. Data observed during this run are shown in Table 1 Three other

TABLE 1.—*Temperature, carbon dioxide, and oxygen concentrations observed during the microbial decomposition of fresh horse manure.*

Date	Hour	Air current, cu. ft./min.	Temperature, ° C		Gas concentrations %	
			Room	Appar.	Carbon dioxide	Oxygen
Apr. 29	6 p.m.*	0.8	27	—	—	—
Apr. 29	9 p.m.	0.8	27	35	6.0	14.4
Apr. 30	10 a.m.	0.8	26	51	12.4	8.0
Apr. 30	10 p.m.	2.1	31	58	9.8	10.2
May 1	8 a.m.	3.2	30	60	7.6	11.8
May 1	9 p.m.	3.4	31	61	6.8	13.0
May 2	8 a.m.	4.0	28	63	6.0	13.0
May 2	10 p.m.	1.9	29	61	8.8	10.7
May 3	11 a.m.	2.4	29	59	8.6	11.1
May 3	10 p.m.	5.2	30	55	1.6	18.0
May 4	10 a.m.	1.3	28	50	9.2	10.4
May 4	10 p.m.	1.4	30	48	8.2	11.8
May 5	10 a.m.	2.5	28	40	3.6	—

*At beginning.

experiments similar to the first one in which fresh horse manure and bedding were used and two experiments in which cornstalks and a mineral salts mixture were used were made. The data obtained in these latter experiments are presented in Table 2. Two other experiments were made to determine the rate of decomposition of fresh manure for comparison with the rate of decomposition of cornstalks. The cornstalks were prepared for the experiment by passing them through a hammer mill and a 1¼-inch screen. The ground cornstalks were then weighed into the churn and nitrogen, phosphorus, potassium, and calcium added as ammo-phos-ko and cyanamide to supply the same amount of nitrogen as that contained in the manure. The moisture content was adjusted to 70% and the apparatus started.

TABLE 2.—*The decomposition of fresh horse manure and cornstalks.*

Exp.	Days	Moisture %		Total dry weight, grams			Loss in dry weight %	Ash in dry matter %	
		Beginning	End	Beginning	End	Loss		Beginning	End
A	7	55	70	11,748	8,417	3,331	28.3	11.25	16.86
B	7	67	70	18,310	14,613	3,697	20.2	12.85	18.55
C	7	66	75	14,081	10,558	3,523	25.0	13.65	17.78
D*	7	—	67	17,432	13,319	4,113	23.5	8.26	18.65
E*	10	—	58	14,465	10,231	4,234	29.3	8.26	15.94

*Cornstalks.

Air was passed into the apparatus at the rate of 5 cubic feet per minute. The air was shut off and the apparatus stopped at intervals for making determinations of temperature and carbon dioxide. The data obtained appear in Table 3.

TABLE 3.—*Rate of accumulation of carbon dioxide after stopping air supply.*

Horse manure and straw bedding after 7 days churning, temperature 48° C		Cornstalks after 3 days churning, temperature 59° C	
Time	CO_2 %	Time	CO_2 %
10:45 a.m.	0.5*	8:59 a.m.	1.2*
11:00 a.m.	3.2†	9:00 a.m.	8.0†
11:20 a.m.	6.0	9:05 a.m.	14.8
11:50 a.m.	7.6	9:10 a.m.	18.0
1:25 p.m.	16.6	9:15 a.m.	19.3
3:30 p.m.	19.8	9:20 a.m.	19.2
4:00 p.m.	19.8		
6:15 p.m.	19.4		
9:15 p.m.	19.4		

*Air was entering at the rate of 5 cu. ft. per minute.
†Air shut off.

Another experiment similar to those described above, except that the apparatus was not revolved during the decomposition, was made. Fifty-five and five-tenths kilograms of fresh horse manure and strawy bedding which contained 65% moisture were placed in the apparatus. The manure packed in by hand completely filled the apparatus. The data obtained in this experiment are shown in Table 4.

RESULTS

The data in Table 1 are typical of five other experiments that were performed. The temperature increased to about 60° C in 24 hours and then gradually decreased until at the end of 7 days it was again at room temperature. The CO_2 concentration increased rapidly, but this may be regulated by the rate of the air supply. The increased supply of air probably dilutes the CO_2 concentration for a cylinder of a specific size, and thus lowers the concentration. The respiratory ratio (CO_2/O) was about the same as that observed by Lambert and Davis (2), although it was never exactly unity. The sum of the O_2 and CO_2 percentages was 19 to 20, instead of 21 which should have been

TABLE 4.—*Temperature and concentration of carbon dioxide observed during the microbial decomposition of fresh horse manure (apparatus stationary).*

Date	Hour	Air current, cu. ft./min.	Temperature, °C		Carbon dioxide %			
					At shaft		At bottom	
			Room	Apparatus	Air entering	2 minutes after air was shut off	Air entering	2 minutes after air was shut off
June 14..	11 a.m.	1.4*	28	—	—	—	—	—
June 15..	8 a.m.	1.4	28	59	8.8	17.6	—	—
June 16..	7 a.m.	2.8	28	57	2.8	17.4	—	—
June 17..	8 a.m.	2.0	29	60	4.4	16.0	16.6	16.2
June 18†	9 a.m.	1.0	29	60	6.2	10.8	9.4	9.6
June 19..	7 a.m.	1.5	29	50	5.2	9.6	9.6	9.6
June 20	8 a.m.	2.0	29	42	0.4	1.4	3.6	3.6
June 21 .	11 a.m.	1.0	27	36	0.5	1.4	3.0	3.0

*Beginning of experiment.
†2 liters of water added.

found if all of the oxygen in the air had been converted to carbon dioxide. Whether the inability to obtain exactly unity was caused by the presence of another gas besides nitrogen was not determined.

Whether the moisture would increase or decrease during a run depended on the provision made for the escape of the exhausted air. Water is an end-product along with CO_2 in the microbial decomposition of organic matter. If it could not escape readily, it would condense on the sides of the walls and increase the moisture content of the material. This situation occurred most readily when the churn walls were cooled by a low room temperature. On the other hand, if the water could be carried off readily, the high temperature of the material would cause a rapid evolution so that the moisture content would be even lower at the end than at the start. Under the conditions of the experiments the moisture content usually increased.

When the apparatus was not revolved, strata appeared in the compost. That is, the manure did not decompose uniformly throughout the mass but layers appeared in which the moisture content, percentage of ash, and microflora were different. The layer of manure immediately surrounding the shaft where the air entered the apparatus was permeated with a heavy growth of "firefang". The temperature and concentration of carbon dioxide were highest in this layer (Table 4). Surrounding this was a layer of yellow strawy material (25% moisture) which showed little or no decomposition. Surrounding the strawy layer was a layer of brown manure which contained 60 to 80% moisture and little or no "firefang". Free moisture collected at the bottom of the churn.

When the manure was revolved continuously, no "firefang" developed. No strata could be discerned and the moisture content of the material was uniform. At the end of 7 to 10 days the material had a dark brown color and the straw was well broken down. If the manure was decomposed more than about 9 days and had a moisture content

of about 70%, there was a tendency to form balls like the original droppings.

The results in Table 2 show that 20 to 30% loss of dry matter occurred in 7 days when the churn was revolved. Dunez (1) studied the microbial decomposition in liter flasks and obtained 22% decomposition of oat straw at 37° C in the first 10 days and 25% decomposition of the same material at 65° C in the next 10 days. According to Waksman and co-workers (4, 6), the increase in ash content should run parallel with the decrease in the organic matter content, since the former does not volatilize. The results reported here follow this supposition more closely than their data, but the results in either case make a correlation of this kind only of slight value. Continued study of this question, however, may be profitable.

The rate of CO_2 evolution was very rapid at the highest temperature and then gradually decreased. Other studies than those reported in Table 3 showed that the CO_2 concentration increased to about 19% in 15 minutes after the air was shut off during the first few days of the experiment. The length of time for the CO_2 to reach 19% after 7 days of churning increased considerably as shown in Table 4. No oxygen could be detected in the air of the compost even though the CO_2 concentration did not reach 20%. This building up of the CO_2 content was much more rapid than that reported by Lambert and Davis (2), who stated that it required 7 hours for the CO_2 to reach a concentration of 20% in the manure heap after turning. The difference in the rate of accumulation of the CO_2 in the manure heap and in the churn is probably because air can diffuse into the heap but cannot diffuse very rapidly into the churn.

DISCUSSION

Aeration and agitation had a favorable effect on the microbial decomposition of organic matter. Rehm (3) studied the effect of aeration and agitation on the multiplication of 16 strains of aerobic bacteria. He used 1-liter florence flasks containing 500 ml. of plain peptone broth. Some flasks were aerated by a current of air, some were agitated, and some were left quiet, but it seems he did not try both aeration and agitation simultaneously. He concluded that both aeration and agitation stimulated multiplication of all organisms tested, the former proving more beneficial. However, he states that both factors are probably important and cannot be separated entirely.

The stratification of the compost which occurred when the apparatus was not revolved is similar to the condition often met with in the compost heap. The "firefang" organism develops in the portion of the manure which is well aerated and tends to dry out the surrounding manure. Decomposition is cut down in this layer and as a result the time of composting is increased. When the apparatus was not revolved the loss in dry weight of the compost after 7 days was 13%, whereas an average loss of about 25% was obtained in 7 days when the apparatus was revolved.

The rapid microbial decomposition obtained when the churn was revolved is probably because the moisture and air were distributed uniformly through the whole mass continuously. Churning the ma-

terial also had a pumping effect, and liberated the gaseous end-products as the material fell over and over. When the moisture content of some of the material becomes less than 40% or when the larger portion of the heap does not obtain a continuous supply of air, there cannot be much aerobic decomposition in that portion. However, in composting for mushroom culture, the heap is turned about four times and well aerated. When the manure is made up into 6-inch beds in the final heating process, a satisfactory amount of decomposition may be secured in most of the material.

The practicability of an apparatus of this kind in commercial mushroom culture is not known at present. Composts prepared in a larger churn, which held ½ ton of manure, at Coatesville, Pa., permitted even a thicker growth of mushroom mycelium than in ordinary composted manure. Mushrooms are growing thickly on this compost, but the yield is not known at this time. The cost of an apparatus of this kind may prove a serious disadvantage, but a practical modification may be possible. Further experiments are being performed.

This apparatus may also be useful in the fermentation of tobacco, coffee, cocoa, and similar waste products, and in the study of spontaneous combustion. It is not hard to imagine how spontaneous combustion might occur if the initial moisture content of the entire material was about 30%. The combustion probably occurs in a zone dried out by an underlying zone of active microbial growth.

SUMMARY

1. An apparatus was described for the rapid, high-temperature microbial decomposition of fibrous or divided cellulosic material.

2. Moisture and air are uniformly distributed in the compost and no firefang occurs.

3. Twenty to 30% loss of dry weight or organic matter was obtained in 7 to 10 days.

4. The evolution of carbon dioxide was very rapid. When air entering at the rate of 5 cubic feet per minute was shut off, the carbon dioxide concentration passed from an initial 1.2% to 19% in 15 minutes.

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NODULATION OF SOYBEANS IN POT CULTURE BY EFFECTIVE AND INEFFECTIVE STRAINS OF *RHIZOBIUM JAPONICUM*[1]

E. W. RUF and W. B. SARLES[2]

IT has been shown that there is a variation in the number, distribution, and size of nodules produced on soybeans by good and by poor strains of *Rhizobium japonicum*, and it is believed that the development of large nodules, relatively few in number, and concentrated on the tap root and first lateral roots is the most desirable type of nodulation.[3] However, the literature is lacking in quantitative data to support this contention.

The present study was undertaken in order to determine the number, volume, weight, and distribution of nodules on roots of soybeans inoculated with good strains as compared with those inoculated with a poor strain of *Rhizobium japonicum*. The relative effectiveness of the strains used was determined by comparing the total nitrogen content and dry weight of the soybean plants grown from inoculated seed with that of plants grown from uninoculated seed.

EXPERIMENTAL

Manchu soybean seeds were disinfected by treatment with 95% ethyl alcohol for 5 minutes followed by calcium hypochlorite solution (containing 2% available chlorine) for ½ hour, and then washed six times in sterile distilled water. The disinfected seed was planted at the rate of 9 seeds per pot in half-gallon glazed earthenware pots filled with nitrogen-poor pit sand that had been sterilized 12 hours at 15 pounds steam pressure.

The first experiment was started September 27 and the plants were harvested November 8, 1935. The second experiment was started March 25 and completed April 29, 1936. Upon conclusion of each experiment the plants were washed from the sand and 50 that appeared representative of each group were selected for nodule location counts and chemical analysis of their tops. The tops were cut off at "ground" level, dried at 37°C for two weeks, weighed, ground, and analyzed for total nitrogen by a semi-micro-Kjeldahl procedure.[4]

RESULTS

The dry weights and total nitrogen contents are shown in Fig. 1. Although the dry weights and nitrogen contents of the plants grown in experiment 2 are consistently higher than those in experiment 1, the same proportionate differences may be noted between plants inoculated with the various strains of root-nodule bacteria used. Strain 507

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[1]Contribution from the Department of Agricultural Bacteriology, University of Wisconsin, Madison, Wisc. Received for publication May 25, 1937.

[2]Graduate Student and Associate Professor, respectively.

[3]FRED, E. B., BALDWIN, I. L., and McCOY, ELIZABETH. Root nodule bacteria and leguminous plants. Univ. Wisc. Studies in Science, No. 5. 1932.

[4]UMBREIT, W. W., and BOND, V. S. Analysis of plant tissue. Application of a semi-micro-Kjeldahl method. Ind. Eng. Chem., Anal. Ed., 8:276–278. 1936.

is definitely poor as shown by the fact that both the dry weight and nitrogen content of plants upon which it has formed nodules are lower than in the case of the uninoculated plants. Strains 9, 18, and 505 may be classed as "good" on the basis of these results.

In making the nodule location counts the root system of each plant was divided into six regions (Fig. 2) and the numbers of nodules in each recorded. These counts are given in Table 1.

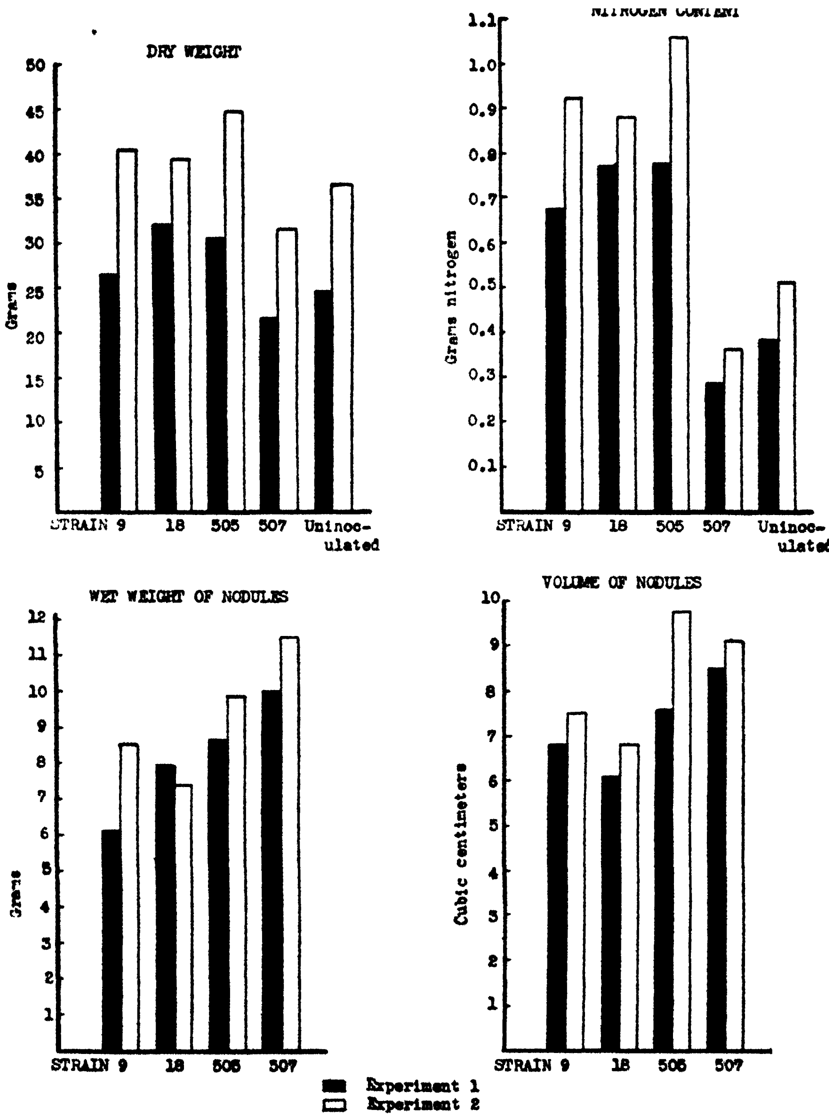

FIG. 1.—Dry weight and nitrogen content of tops, wet weight, and volume of nodules from 50 soybean plants.

TABLE 1.—*Number of nodules per plant on soybeans inoculated with effective and ineffective strains of Rhizobium japonicum, mean of 50 plants.*

Nodule location	Strain 9	Strain 18	Strain 505	Strain 507
Experiment 1—Sept. 27 to Nov. 8, 1935				
A-1	13.00	10.74	7.60	4.72
A-2	1.38	0.84	1.94	14.20
B-1	—	—	0.82	4.54
B-2	—	—	—	15.62
C-1	—	—	—	2.70
C-2	—	—	—	0.62
Total nodules per plant	14.38	11.58	10.36	42.40
Experiment 2—March 25 to Apr. 29, 1936				
A-1	8.54	9.12	9.28	7.50
A-2	4.56	1.34	1.24	11.18
B-1	2.06	0.52	0.36	14.62
B-2	1.32	0.26	0.26	13.18
C-1	0.28	—	—	6.34
C-2	—	—	—	2.14
Total nodules per plant	16.76	11.24	11.14	54.96

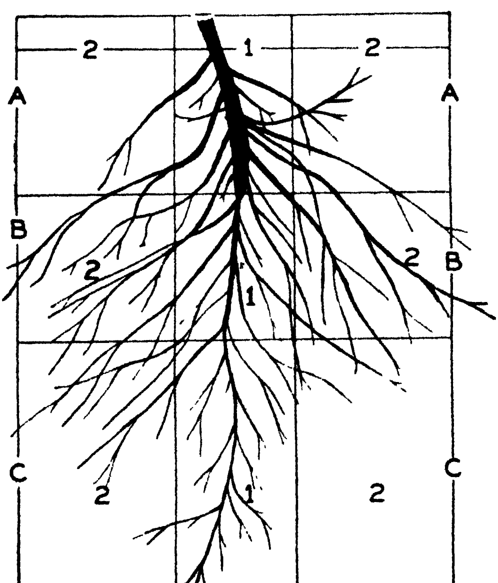

FIG. 2.—Diagram of a soybean root system divided into six regions for nodule location counts.

With strains 9, 505, and 507, a slightly greater number of nodules was formed in the second experiment than in the first, but strain 18 produced approximately the same number of nodules per plant in each case. More important than this, however, is the fact that the location of the nodules produced in each experiment was not significantly different. It is true that in experiment 2, when better growing conditions prevailed, the good strains produced a few nodules in the B-1, B-2, and C-1 positions, but the major proportion of the nodules on these plants was still found on or near the tap root on the upper part of the root system. Nodules formed by the poor strain, number 507, were always small, and were found scattered over the entire root system.

Following the location counts, the nodules were carefully removed from the roots, their wet weight determined, and their total volume

measured. The weights and volumes of nodules from each group of 50 plants are shown in Fig. 1.

Each strain produced a greater volume of nodules in experiment 2 than in experiment 1, but in most cases the poor strain produced the greatest volume. In experiment 2, strain 505 produced a slightly greater volume of nodules than strain 507. As may be seen by referring to Table 1, the nodules produced by strain 505 in experiment 2 were very large because there were only 11.14 per plant, and this small number displaced a greater volume of water than the 54.96 nodules per plant formed by strain 507 in the same experiment. Further comparison of the data in Table 1 with those of Fig. 1 reveals that, although the number of nodules per plant produced by the poor strain averages from three to four times that formed by the good strains, the volume of nodule tissue does not vary so widely. This indicates the fact that the nodules formed by the good strains used in these experiments are much larger than those formed by the poor strain that was employed.

The differences between the wet weights of nodules produced by the good strains and the poor strain are slightly greater than the variations noted in the volume of nodules. The poor strain produced a greater weight of nodules than the good strains in each experiment. The wet weights of the nodule tissue agree more closely with the number of nodules than with the values for the volume of nodules.

SUMMARY

Pot experiments with Manchu soybeans performed in both fall and spring showed that three effective strains of *Rhizobium japonicum* (Nos. 9, 18, and 505) produced relatively few, large nodules, the majority of which were located on, or in the immediate vicinity of, the tap root near the surface of the soil. The ineffective strain used (No. 507) produced many small nodules that were scattered over the entire root system. The ineffective strain produced a greater number, volume, and weight of nodules on each plant than the effective strains. The relative effectiveness of the strains used was determined by comparing the dry weight and nitrogen content of plants grown from inoculated seed with that of plants grown from uninoculated seed.

THE EFFECT OF SOIL TREATMENT IN STABILIZING YIELDS OF WINTER WHEAT[1]

L. B. MILLER and F. C. BAUER[2]

THE hazards of crop production are many and either failure or overproduction of a given crop may cause great inconvenience and loss to farmers and to the entire nation.

The purpose of this paper is to point out the effect of soil treatment upon the regularity or stability of winter wheat production over a period of years and on numerous different soil conditions in Illinois.

SOURCE OF DATA

The crop yield data used in this study were secured from the soil experiment fields operated by the Illinois Experiment Station, most of which were established during the years 1910–15. The crops included in the discussion are those of the 15-year period ending in 1935,[3] hence, the plats were well established by several years of preliminary cropping prior to 1919, the first season from which data are used. A few substitute crops have been grown where failure was almost complete and these were omitted from the averages. Whenever such omissions were made, the results of an earlier season were used to complete the 15-year sample. The fields were laid out so that each crop of the rotation used was represented each year. Most of the harvests were made from plats one-tenth acre in size. A few fifth-acre and a few twentieth-acre plats were used.

SOIL TREATMENT

Plats 1, 5, and 10 in each series are untreated. Plats 2, 3, and 4 receive animal manure usually once during each 4-year rotation in amounts equal in weight to the crops removed. Plats 6, 7, 8, and 9 are residue plats receiving additions of organic matter in the form of cornstalks, second growth clover, and a legume catch crop (usually sweet clover) wherever it can be conveniently used in the rotation. Applications of limestone are made as needed to plats 3, 4, 7, 8, and 9 (called the limed plats) and generous applications of rock phosphate were made to plats 4, 8, and 9 (the phosphate plats). Potash is regularly used on plat 9. Expressed by the usual symbols the soil treatments on the entire series on all fields have been as follows: Plat 1, check; plat 2, M; plat 3, ML; plat 4, MLP; plat 5, check; plat 6, R; plat 7, RL; plat 8, RLP; plat 9, RLPK; and plat 10, check.

EXPERIMENTAL RESULTS

Winter wheat yields for the 15-year period ending in 1935 have been studied on 18 soil experiment fields in Illinois located as indicated on the map (Fig. 1). They represent a range of latitude of more than 300 miles and include many distinctly different soil conditions. The plats were established primarily to study the merits of the soil treatment systems as they affected crop yields and economical use of

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Received for publication May 24, 1937.

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[3]Yield data published in Illinois Experiment Station Bulletins 273, 280, 296, 305, 327, 347, 370, 382, 398, 402, and 425.

land. They offer, after these many years of cropping, a unique opportunity to study crop hazards and stability of production on a given soil type and with the various treatments used.

The 15-year average level for each treatment was calculated for each field. The annual variation in yield from this average was determined and reduced to percentage of the average yield level.

The average percentage of fluctuation for the 15-year period was calculated from the annual percentage variation. Annual fluctuations exceeding 40% have been singled out for the purpose of discussion. They were usually distributed with approximately equal frequency above and below the average. The last column in the accompanying tables gives the number of times in which the yields were below the 40% fluctuation level.

Space does not permit the presentation of all the data studied, but Tables 1, 2, 3, and 4 give the summarized material for four widely separated fields, typical of the results for their respective soil and geographic locations.

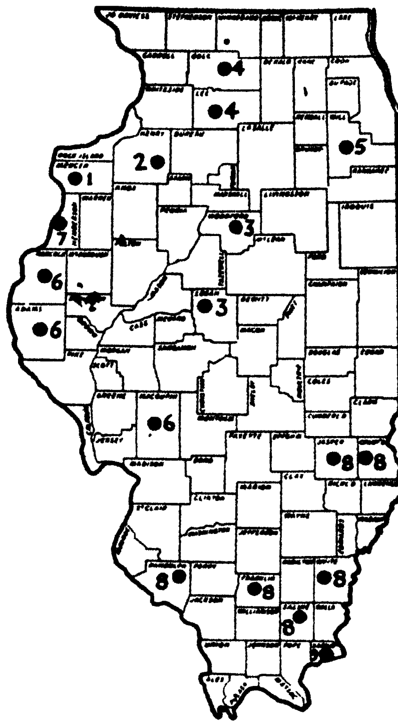

FIG. 1.—Location of the 18 soil experiment fields from which data were used. The numbers indicate the soil group represented by each field.

TABLE 1.—*Results at Aledo in Mercer County dark soil with heavy noncalcareous subsoil.*

Plat	Soil treatment	Av. yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 40%
				0-10	10-25	25-40	40-55	55-70	
1	O	30.1	19.4	6	5	2	2	–	1
2	M	35.3	18.8	3	8	3	1	–	–
3	ML	38.2	18.9	4	6	3	2	–	1
4	MLP	39.0	16.6	5	6	2	2	–	1
5	O	29.3	24.0	2	8	3	1	1	–
6	R	30.7	20.3	6	4	3	1	1	–
7	RL	36.2	21.0	4	5	5	1	–	–
8	RLP	38.5	17.2	8	3	1	3	–	2
9	RLPK	39.7	16.1	7	5	1	2	–	1
10	O	28.9	25.5	5	2	4	2	2	2

TABLE 2.—*Results at Mt. Morris in Ogle County dark soil with open noncalcareous subsoil.*

Plat	Soil treatment	Av. yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 40%
				0–10	10–25	25–40	40–55	55–70	
1	O	22.0	35.0	–	4	6	2	3	3
2	M	27.4	26.8	2	5	5	2	1	2
3	ML	33.3	25.5	4	1	8	–	1	1
4	MLP	33.9	24.4	2	6	6	–	1	1
5	O	21.7	34.9	1	5	3	4	2	4
6	R	23.1	33.7	1	4	3	7	–	4
7	RL	30.0	28.2	3	3	5	3	1	2
8	RLP	33.0	26.1	3	4	6	2	–	1
9	RLPK	34.3	23.0	3	5	5	2	–	1
10	O	20.8	35.7	3	4	–	4	4	4

TABLE 3.—*Results at Carlinville in Macoupin County dark soil with impervious noncalcareous subsoil.*

Plat	Soil treatment	Av. yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 40%
				0–10	10–25	25–40	40–55	55–70	
1	O	18.9	29.3	5	2	3	3	2	3
2	M	25.3	18.5	5	6	2	2	–	1
3	ML	31.8	19.3	3	8	3	1	–	1
4	MLP	32.2	19.7	4	6	4	1	–	1
5	O	20.4	28.3	4	3	3	4	1	2
6	R	20.2	28.4	4	2	5	1	3	2
7	RL	28.1	14.8	5	7	3	–	–	–
8	RLP	31.7	18.7	5	5	5	–	–	–
9	RLPK	32.4	18.5	3	8	4	–	–	–
10*	O	—	—	–	–	–	–	–	–

*Discontinued in 1932.

The average percentages of fluctuation for the various treatments on the four fields reported are plotted in Fig. 2 and indicate the striking differences in stability of production for these soil conditions and treatments.

The soils on the 18 fields used in this study have been classified into nine soil groups. These groups, together with the names of the fields in each, are as follows:

Group 1.—Dark soils with heavy, noncalcareous subsoils:
Aledo, Mercer County

Group 2.—Dark soils with noncalcareous subsoils:
Kewanee, Henry County

Group 3.—Dark soils with heavy, calcareous subsoils:
Hartsburg, Logan County Minnok, Woodford County

Group 4.—Dark soils with open, noncalcareous subsoils:
Dixon, Lee County Mt. Morris, Ogle County

TABLE 4.—*Results at Oblong in Crawford County gray soil with impervious noncalcareous subsoil.*

Plat	Soil treatment	Av. yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 40%
				0–10	10–25	25–40	40–55	55–70	
1	O	9.5	46.0	6	–	2	1	6	5
2	M	13.1	43.9	1	5	1	2	6	3
3	ML	25.2	32.3	4	1	4	5	1	3
4	MLP	29.2	25.5	2	6	3	4	–	2
5	O	9.1	46.2	1	1	2	7	4	5
6	R	12.2	37.7	1	6	2	3	3	3
7	RL	21.3	23.8	3	6	2	3	1	1
8	RLP	27.5	25.7	3	4	5	3	–	1
9	RLPK	30.2	22.7	5	5	3	2	–	1
10	O*	9.9	37.2	2	2	6	2	3	4

*Slightly better drained than the other untreated plats.

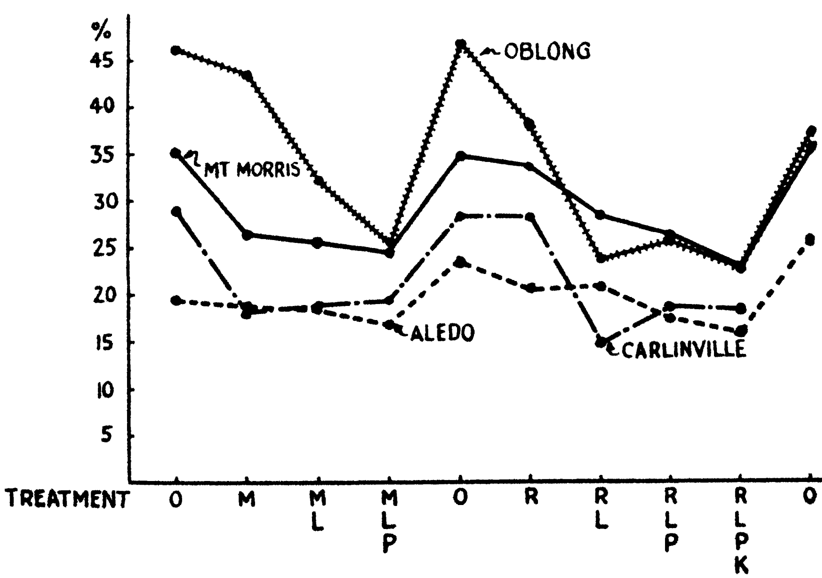

FIG. 2.—Percentage deviation of wheat yields, 15-year period. Soil treatments indicated at bottom of graph.

Group 5.—Dark soils with heavy, impervious, calcareous subsoils:
Joliet, Will County

Group 6.—Dark soils with impervious, noncalcareous subsoils:
Carlinville, Macoupin County
Carthage, Hancock County
Clayton, Adams County

Group 7.—Sandy loams and sands:
Oquawka, Henderson County

Group 8.—Gray and yellowish-gray soils with impervious, noncalcareous subsoils:
Enfield, White County
Newton, Jasper County
Ewing, Franklin County
Raleigh, Saline County
Oblong, Crawford County
Sparta, Randolph County

Group 9.—Hilly, forest, orchard and pasture land:
Elizabethtown, Hardin County

The average yields and percentages of fluctuation for the soil groups are given in Tables 5 and 6. They are arranged in the order of decreasing productivity levels of check plats. It is unfortunate that some of the groups are represented by only one field. However, the similarity of performance of individual fields within those groups having more than one representative indicates that each field is a fairly reliable sample.

TABLE 5.— *Yields of wheat in bushels per acre for soil groups, 15-year average.*

Soil treatment	Soil group numbers								
	1	2	3	4	5	6	7	8	9
O	30.1	28.0	26.6	22.6	19.4	18.4	9.8	5.4	——*
M	35.3	32.7	30.6	29.7	23.2	23.6	14.2	8.9	8.7
ML	38.2	35.8	32.7	34.0	26.2	29.0	21.8	22.4	16.9
MLP	39.0	40.5	33.6	35.2	32.6	30.4	22.6	25.7	22.9
O	29.3	28.6	27.4	22.9	18.0	18.7	11.5	5.7	5.8
R	30.7	31.5	30.9	24.8	20.0	20.5	12.6	6.8	5.6
RL	36.2	35.1	28.4	30.4	21.6	27.6	19.8	18.0	11.9
RLP	38.5	40.7	31.7	33.3	33.3	29.7	19.2	22.2	20.6
RLPK	39.7	41.7	31.9	34.9	37.0	32.0	19.9	27.1	22.5
O	28.9	——*	26.4	21.4	21.1	19.5	——*	6.7	——*
Average of untreated plats	29.4	28.3	26.8	22.3	19.5	18.9	10.7	5.9	5.8

*Plat discontinued before 1935.

DISCUSSION OF RESULTS

Winter wheat grown on fertile soils was consistently high yielding. The average yield for the 15-year period on the untreated soil of groups 1, 2, and 3 was approximately 28 bushels an acre with a high degree of stability. The Aledo field (Table 1) is typical of the better dark-colored soils of the central part of the state and its average

TABLE 6.—*Yield fluctuations for soil groups, 15-year average percentages.*

Soil treatment	Soil group numbers								
	1	2	3	4	5	6	7	8	9
O	19.4	16.5	21.3	32.3	33.2	30.6	40.4	68.4	—*
M	18.8	14.7	20.0	23.4	30.2	26.3	34.7	58.1	61.0
ML	18.9	12.5	15.9	21.4	28.6	23.2	31.3	35.8	43.7
MLP	16.6	11.7	16.6	19.7	22.7	23.0	33.2	31.7	39.1
O	24.0	18.5	18.3	31.8	40.5	28.7	39.5	65.0	81.6
R	20.3	19.7	13.9	29.3	36.4	26.5	46.5	62.4	88.0
RL	21.0	18.2	14.8	24.1	31.8	21.8	35.8	34.2	35.3
RLP	17.2	15.1	14.8	22.7	18.1	23.7	37.1	33.7	33.6
RLPK	16.1	14.7	12.6	19.8	14.6	21.6	31.8	28.0	34.3
O	25.5	—*	17.0	31.7	29.3	31.8	—*	63.7	—*
Average of untreated plats	23.0	17.5	18.9	31.9	34.3	30.4	40.0	65.7	81.6

*Plat discontinued before 1935.

check plat fluctuation is only 23%. On the average, there was only 1 year in 15 when the check plat yields varied 40% or more below their average production.

At Mt. Morris (Table 2) the soil is also dark in color and high in fertility, but wheat yields on untreated land are much less stable. In 6 years out of 15, fluctuations were greater than 40% and 4 of these were downward. It was found that soil treatment reduced the fluctuation greatly, the minimum being only 23% on plat 9 (RLPK). During the 15-year period fluctuations exceeding 40% occurred only twice on this plat. Limestone with organic matter was also very effective in increasing yields and in decreasing variation. The Mt. Morris field is near the northern edge of the winter wheat growing area and winter injury is a serious hazard, though the wheat varieties used were selected for winter-hardiness.

The field at Carlinville is located in the wheat growing section of southwestern Illinois. On untreated land there were 5 seasons during the 15 under observation when fluctuations exceeded 40%. Half of these extreme fluctuations were above and half of them below the average level (Table 3). Treatment with lime and organic matter greatly stabilized production. On three of the five limed plats there were no fluctuations exceeding 40%. High fluctuation (greater than 40%) was shown once by each of the other limed plats.

The untreated land at Oblong (Table 4) produced an average yield of 9.5 bushels of wheat an acre with an average fluctuation of 43.5% for the entire period. There were 4 years during the 15 when production was 40% or more below the 9.5 bushel average. Every treatment gave increased yields, the maximum yield being 30.2 bushels as an average for 15 years on plat 9 (RLPK). Fluctuation on this plat was the lowest for the field, averaging 22.7% with but 1 year in 15 when production fell more than 40% below the average level of 30.2 bushels. Results at Oblong are typical of those on the other southern Illinois

fields of soil group 8, which is characterized by light-colored surface and impervious, noncalcareous subsoil.

On sandy land at Oquawka in Henderson County the untreated plats made an average yield of 10.6 bushels an acre with an average fluctuation of 40%. Organic matter and limestone were very effective in increasing yields, bringing the production for these plats up to the 20-bushel level. The stability of production, however, was not greatly improved by soil treatment.

Similarly, on hilly land in Hardin County, yields were increased by soil treatment but fluctuations continued to be high even on those plats which produced good average yields.

GENERAL COMMENTS

In this long-time study there were a number of irregularities in the data which should be recognized. Varieties of wheat were changed from time to time and on some fields the crop rotation was altered and variations were made in the amount and method of fertilizer application. The same general treatment, however, continued on each plat throughout the entire 15-year period and for several seasons prior to the first one for which data were used. This preliminary cropping period tended to establish the yield level for each treatment on the different fields, so that the yields during the first years of the period studied were similar to the average for the 15 seasons.

Further consideration of the data used and of the notes taken for each crop should be made in order to correlate the various hazards of growing wheat with the success of overcoming these hazards through soil treatment. Such an analysis, however, is beyond the scope of this paper which is limited to the study of all hazards combined.

CONCLUSIONS

1. Fertile, well-drained soils produced high average yields of wheat with a high degree of regularity from year to year.
2. Untreated infertile soils were very irregular in wheat production.
3. With the exception of sandy land and hilly land, all other poor or intermediate soils studied showed a high degree of improvement in stability of wheat production when they were treated in such a way as to maintain a fairly high production level.
4. Occasional wheat failures or near failures occurred even on the most productive soils and under approved farming methods.
5. Good farming was rewarded by higher wheat yields as well as by fewer seasons of crop failure.

STUDIES OF QUALITY IN CANNING CORN[1]

C. W. DOXTATOR[2]

CANNED sweet corn must be of high quality to be satisfactory for human consumption. In estimating quality in canned corn there are several characteristics which are of importance, namely, tenderness of pericarp, sweetness, consistency of kernel contents, and flavor of product. These characteristics vary with the stage of development of the ear of corn and it is necessary, therefore, to determine with great care the picking date which will give the highest quality canned product. Certain varietal differences in quality at canning stage of development have been recognized in the past (3, 4),[3] but few studies have been reported in which the objective was to determine differences in tenderness at canning stage between different varieties of sweet corn.

With the increasing use of whole grain style canned corn, tenderness of product becomes increasingly important. If there are differences in tenderness between different hybrids of sweet corn at a definite stage of development, such information would be of great importance. The plant breeder would then be in a position to develop hybrids which excel in this property. In this study the main purpose was to investigate the problem of tenderness in a series of Golden Bantam inbred lines, and hybrids between them, with the view of establishing suitable methods for determining tenderness, as well as to determine differences in tenderness which might exist between these cultures.

LITERATURE REVIEW

In studying quality of sweet corn for canning, one of the first problems encountered was that of finding a rapid and accurate method for determining differences in tenderness. Rosenbaum and Sando (19) used a modified Joly balance fitted with puncturing needle in determining resistance to puncture in tomatoes in an effort to correlate toughness with resistance to infection of *Macrosporium tomato* Cooke. Hawkins and Harvey (7), in studies of resistance of potato tubers to *Pythianum debaryanum* Hesse, and Hawkins and Sando (8) in studies of resistance to wounding in small fruits and cherries, used a similar puncturing device. Rudnick and Bakke (20) made use of this idea and devised a similar puncturing machine for a study of the resistance to puncture of the pericarp of sweet corn. In this study the corn pericarp was stripped from the kernels, glued to a cork which

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[3]Figures in parenthesis refer to "Literature Cited", p. 752.

had been prepared as a puncturing stand, and punctured with a glass needle. They observed an increase in the resistance of the pericarp to puncture with increasing maturity of the corn.

Although these investigators had used certain puncturing devices, all were undesirable for use in sweet corn studies. Culpepper and Magoon (3), in a comprehensive study of the relative merits of sweet corn varieties and the relation of maturity of corn to quality of canned product, used a much more practical instrument for tenderness studies. This instrument consisted of a glass tube 13 inches long and ¾ inches in diameter, within which an aluminum rod plunger $\frac{3}{16}$ inch in diameter was placed. This plunger was attached at the upper end to a coil spring made of No. 22 steel piano wire which was also fitted inside the glass tube. The lower end of the plunger was fitted with a puncturing needle of No. 16 gauge brass wire. The glass tube was graduated in grams and an indicator attached to the upper end of the plunger. The lower end of the coil spring was attached to the glass tube. A guide cap was also placed at the lower end of the glass tube to center the plunger rod. Kernels of corn were punctured on the ear. By the use of this machine a large number of measurements could be made within a very short space of time. These investigators observed that, "in general there is a relation between the resistance to puncture of the fresh corn and the toughness of the canned product made from it". They found, however, little variation between varieties harvested at the same age, with the exception of Crosby which was distinctly tougher than other varieties. They also concluded that factors other than toughness of pericarp might affect the texture of the canned product.

These same authors (16), in a study of Golden Bantam and Stowell's Evergreen, observed that varietal differences did exist in toughness as measured by the puncture machine and suggested that differences might exist between strains of the same variety. Seasonal factors, the most important of which was temperature, were found to affect greatly the tenderness of corn at canning stage. In a third article, these authors (4) emphasized the importance of the underlying structures of the corn kernel as well as the pericarp in the determination of tenderness by means of the puncture machine. They pointed out that, although some slight error was introduced in pericarp tenderness determinations because of the structure of the kernel contents, it was not of great importance because, in their experience, puncture test readings furnished a very reliable index of tenderness of cut corn. They point out also that, since tenderness is the most important single factor influencing quality of product, an endeavor should be made to breed more tender strains of sweet corn.

Metzger (17), in a study of the relation of fertilizers to yield and quality of sweet corn, used puncture tests to determine tenderness of corn from different fertilizer treatments. He was unable to determine any difference in tenderness, although many hundreds of measurements were made.

Appleman (1) attempted to forecast the best canning stage for sweet corn by use of temperature records. He discussed also the "thumb nail" test as an aid for selecting sweet corn at the most desirable canning stage. This simple test is applied by cutting the top of the kernels of an ear with the thumb nail and pressing out the kernel contents. Using this test, he classified corn into four groups, *viz.*, premilk, milk, early dough, and dough. He determined the percentage of moisture, total sugars, and starch on these four classes, and emphasized the fact that the reliability of the thumb nail test is greatly influenced by seasonal temperature.

Morphological and histological studies have been made on the kernels of both field and sweet corn. Burton (2) found that the hull of Country Gentleman sweet

corn did not thicken with the development of the kernel. From certain chemical studies crude fibre of the hull appeared constant at all maturities. He observed that with increasing maturity the hull of corn lost moisture. Haddad (6) studied the morphological development of sweet corn pericarp in two inbred lines and their F_1 hybrid. He found that the number of layers of cells in the ovary wall was the same in both inbred lines and the hybrid. He also found that the ovary wall increased in thickness for a time in development and later decreased in thickness with increasing maturity. The hybrid matured more rapidly than the inbred lines and the ovary wall was thinner at all stages ot development than in the parent lines. He used a puncture machine similar to that of Culpepper and Magoon (3) and observed differences in resistance to puncture in his cultures harvested at canning dates. He found that after the 15-day stage of development for the two inbreds, and after the 10-day stage for the hybrid, the ovary wall increased in toughness while decreasing in thickness.

Lampe (15) described the development of the endosperm of various types of maize and emphasized the importance of recognizing regions in which sweet corn may be grown where the most desirable quality of product can be produced. Johann (12), in a study of the caryopsis of yellow dent corn with reference to resistance to attacks of kernel rots, observed that the pericarp is made up of spongy cells which gradually disappear as development proceeds; and at maturity the pericarp is composed of compact thick-walled pitted cells.

With the development of the present-day inbreeding and hybridization methods in corn improvement, a large number of studies in inheritance of economic characters in both field and sweet corn have been reported. Jenkins (11) obtained positive correlations between parents and crosses for the 19 characters which he studied in field corn. Nine of the 19 characters of the parents were positively and significantly correlated with yield in the crosses. Nilsson-Leissner (18), Jorgenson and Brewbaker (14), and Hayes and McClelland (9) all have demonstrated a relationship between parent inbred lines and their F_1 crosses for yielding ability or other characters of corn.

Recently, Johnson and Hayes (13) determined parent progeny relationships for yield in Golden Bantam sweet corn. Positive and significant correlation were obtained for yield between parent lines and crosses. Seven plant characters of the inbred were also correlated with yield in the top cross. In general they found no striking relation to the top cross yield with any of these characters.

MATERIALS AND METHODS

MATERIAL

The studies herein reported are confined to inbred lines and crosses of Golden Bantam sweet corn grown at University Farm, St. Paul, Minnesota, during the seasons of 1929 to 1933.

Twelve inbred lines were available for use in this study. Nine of the 12 lines had been inbred four generations and the other three a somewhat longer time. All inbred lines were distinctly different in character of plant growth and exhibited marked uniformity within the lines. All were similar in maturity to the canning strain of Golden Bantam. Sixty-six single crosses are possible with 12 inbred lines $\frac{1}{2}$ n (n−1). Crossed seed was obtained for the 1929 test season on 62 of the possible 66 crosses, and in 1930 seed of 64 crosses was available. In the later years, 1931, 1932, and 1933, a few selected crosses and their parents were used for study.

Standard Golden Bantam (canning strain) was included in all tests as well as several other crosses of Golden Bantam which were somewhat later in maturity.

FIELD AND LABORATORY METHODS

In 1929 and 1930 all inbred lines and crosses were planted in single-row plats of 12 hills each and bordered on each side by a row of standard Golden Bantam. Two replications were used for the inbreds and three replications for the crosses. Hills were spaced 3½ feet apart each way. In 1929 and 1930 only two- and three-stalk hills surrounded by corn on all sides were harvested for quality and yield data. In later seasons three replications of three-row plats 12 hills long spaced 3½ feet apart each way were used for all cultures. Only three-stalk hills surrounded by corn on all sides were harvested after 1930. Since five kernels were planted per hill and later thinned to three plants, there were good stands for harvest in all tests, with but very few exceptions.

Accurate silking notes were taken on all test material grown. This information was used at canning harvest time, along with general ear characteristics, such a color of ear, plumpness of kernel, and distance between the rows, for determining approximate canning date. Golden Bantam corn is considered to be at best canning stage a day or two later than the stage at which it is considered prime for table corn on the cob. When a culture appeared to be near table corn stage the "thumb nail" test (1) was used to determine thickness of kernel contents. When the consistency of kernel contents was that of a very thick cream for a fair sample of the ears of a culture, the culture was considered prime for canning. The selection of harvest date on canning material is obviously of vital importance and a real effort was made to harvest all cultures at as nearly the same stage of maturity as possible. Each replicate was harvested and handled separately. The weight of unhusked corn, husked corn, cut corn, and cobs was obtained for yield and other determinations. The cut corn from all replicates of a culture was then bulked and a sample taken for canning. In the 1929 season the corn was canned cream style. In all later seasons all canning was done by the whole-grain method.

A puncture test machine similar to the one used by Culpepper and Magoon (3) was used to puncture kernels on the ear for tenderness determinations. After the corn had been husked all ears of each replicate were arranged on a table in order of apparent maturity and four representative ears selected for puncturing. Six puncture readings were taken on each of the four ears selected. Care was used to puncture only kernels on the central portion of each ear, as the silks on this portion of the ear are pollinated first (3). Preliminary investigations on Golden Bantam showed some variation of resistance to puncture on kernels of a single ear. This variation was reduced appreciably by the elimination of the butt and tip kernels from the puncture tests. Readings on resistance to puncture were recorded to the nearest 10 grams. Thus, 24 puncture determinations were made on the four ears from each plat or a total of 96 punctures on the three replicates of each culture. In 1933, in studying date of harvest in relation to tenderness, 10 punctures were taken on each of four ears from each of three replicates.

The canned corn from each culture was later subject to chewing tests by at least two persons. Each operator graded the canned product for tenderness independently on a scale of 10, where 10 was the most tender and 1 the toughest. In all cases the grading was done without the knowledge of the puncture index on the culture being tested.

During the 1931, 1932, and 1933 seasons moisture determinations were made

on duplicate samples of cut corn from each culture. The Brown Duval moisture tester commonly used for determining moisture percentage in shelled grain was used for this work. Due to the foaming of the cut corn samples in the tester, the size of sample was reduced from 100 to 20 grams. In the study of relation of maturity to tenderness conducted in 1933, duplicate moisture tests were run on each of the three field replicates of each culture. Cut corn containing 69% moisture was taken as the correct moisture content for prime canning corn. In the seasons of 1931, 1932, and 1933 all cultures were harvested as nearly as possible at this moisture content.

In the analysis of the data obtained the methods of the analysis of variance of Fisher (5) were used. Significant differences were determined from values of F using the tables given by Snedecor (21).

EXPERIMENTAL RESULTS

PUNCTURE INDEX OF INBRED LINES AND CROSSES FOR 1929 AND 1930

In the 1929 and 1930 seasons all 12 inbred lines of Golden Bantam and all single crosses of which there was seed available were grown for tenderness studies. The puncture data were recorded and average data for the two years are given in Table 1. All indices are given in grams required to puncture the kernel. Most of the indices of the crosses, with the exception of those starred, are averages of 192 determinations by the puncture machine.

TABLE 1.—*Average puncture indices for inbred lines, F_1 crosses, and averages of F_1 crosses of Golden Bantam sweet corn (av. 1929–30).*

Inbred line number												Inbred line number	Puncture index of:	
38	40	41	42	43	44	45	46	47	48	49	50		Inbred line	Av. of F_1 crosses
	344	339	356	374	353	372	393	343	338	348	368	38	306	357.1
		290	346	346	341	352	355	345	320	345	357	40	388	340.1
			324†	341†	308†	323	351	311	338	320	362	41	324	329.1‡
				368	333	335	362	364	346	331	358*	42	328	348.2‡
					329*	365	382	352	369	380	396	43	374	365.5‡
						333	363	316*	326*	344	288	44	362	332.8‡
							378	349	360	370	378	45	362	355.9
								377	359	367	387	46	370	370.4
									321	349	356	47	342	345.2‡
										339	338	48	333	342.3‡
											372	49	348	351.4
												50	395	369.6‡

*Not tested in 1929.
†Not tested in 1930.
‡Weighted averages.

The parent variety, Golden Bantam, had an average puncture index for the two years of 356 grams. The 12 inbred lines which were selected through inbreeding from Golden Bantam averaged 352.6 grams. Six lines were lower and six were higher in puncture index than the parent variety. Thus it appears that these 12 inbred lines are a

fair sample of the inbred lines which could be obtained from this variety of sweet corn. In studying all possible crosses of these 12 lines it would be expected, therefore, that the average of all crosses should be very nearly the same as that of the parent variety, and of the average of the 12 inbred lines themselves. The average puncture index of the 66 crosses was 349.1 grams, a close approach to expectation. The range of puncture index of the 12 inbred lines and their 66 crosses was also very similar, being from 306 to 395 grams for the inbreds and from 288 to 396 grams for the crosses.

In order to determine whether significant differences had been obtained between the crosses, an analysis of variance was made for each of the two years of test. These analyses are given in Table 2.

TABLE 2.—*Analyses of variance of puncture indices on Golden Bantam crosses in 1929 and 1930.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares	F	Standard error
		1929			
Replicates	2	382.9	191.4	.63	—
Crosses	52	153293.2	2947.9	9.76*	—
Error	104	31413.0	302.1	—	10.0
Total	158	185089.1			
		1930			
Replicates	2	1022.8	511.4	1.97	—
Crosses	60	86194.3	1436.6	5.52*	—
Error	120	31214.5	260.1	—	9.3
Total	182	118431.6			
Av. 1929 and 1930					7.8

*Exceeds the 1% point.

It is of interest to note that the variation between replicates was not statistically significant in either of the two years. Apparently the soil variation between these two replicates was not such as to affect resistance to puncture. The variation due to crosses was found to be highly significant in both years. An examination of Table 1 shows that with the odds of 20:1 there were 16 crosses significantly lower in puncture index than normal Golden Bantam, 46 crosses not significantly different, and 4 crosses significantly higher than Golden Bantam.

In comparing mean squares for crosses in the two years it would appear that there were wider differences in 1929 than there were in 1930. Although both seasons were satisfactory for development of corn after pollination, conditions in 1930 were not quite so favorable as in 1929.

It has been observed (3, 4, 6), however, that resistance to puncture increases with the development of the corn kernel. Although great care was taken to harvest all crosses at a definite stage in development by use of the characteristics of ear and kernel previously

described, it is possible that some variation was introduced. The date of harvest was determined in each year of test solely upon the ear and plant characteristics for that year. The 1930 harvest dates can therefore be considered as independent of the 1929 harvest dates. As a check upon the validity of the average data given for all crosses, the interannual correlation for puncture test for the 60 crosses grown in both years was determined. The correlation coefficient obtained was +0.4096 (1% point. .3248). Since yields of cut corn were obtained on all crosses tested, it was also possible to obtain the interannual correlation for yield. The figure obtained was +0.250. It appears, therefore, that the data which were obtained for tenderness in the crosses were at least as satisfactory as that obtained for yield. Although both correlations are somewhat low, the difference between the correlations suggests that soil and climatic conditions probably have less effect on tenderness than on yielding ability.

STUDIES OF PUNCTURE INDEX AND CHEWING TESTS OF SELECTED CROSSES, 1929–1933

On the basis of the yield and other data obtained in 1929 and 1930, 10 crosses and normal Golden Bantam were selected for test in 1931, 1932, and 1933. Three of the crosses used in this study, 72×77, 72×81, and 77×78, were of slightly later in maturity than the other seven. The analysis of variance for these trials is shown in Table 3.

TABLE 3.—*Analysis of variance for puncture tests of 11 selected cultures tested for five years, 1929–1933.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares	F	Standard error
Replicates. .	2	118	59	.26	—
Replicates × years	8	2680	335	1.45	—
Years. . .	4	12072	3018	13.06*	—
Cultures .	10	43778	4378	18.95*	—
Cultures × years. .	40	49813	1245	5.39*	—
Error.	100	23059	231	—	3.9
Total.	164	131520			

*Exceeds the 1% point.

From the analysis given in Table 3 it appears that the cultures differed very significantly in resistance to kernel puncture. The highly significant interaction of cultures and years suggests that the different cultures reacted differently to puncture in certain years. Comparing the variance for cultures with that for cultures×years, the difference is also highly significant. It is apparent, therefore, that while these cultures reacted in a significantly differential manner in different years the variance due to cultures was so high as to indicate that some of the differences between cultures were permanent features of these lines. The highly significant F value for years, obtained in this analysis, indicates a very distinct seasonal difference for all cultures. It is noted again that variation between replicates was not significant.

Since chewing tests were made in all tests on these same cultures,

the relationship of puncture test to chewing tests could be studied also. In the chewing tests, tenderness was graded from 10 (tender) to 1 (tough). Since all three field replicates of each culture were bulked for canning and the canned samples graded, only variation due to cultures and years could be studied. In Table 4 is given the analysis of variance for these chewing tests.

TABLE 4.—*Analysis of variance for chewing tests on 11 cultures in the five year test period, 1929–1933.*

Variance due to	Degrees of freedom	Sum of squares	Mean squares	F
Years	4	15.382	3.8455	3.38*
Cultures	10	20.806	2.0806	1.83
Error	40	45.558	1.1389	—
Total	54	81.746		

*Exceeds the 5% point

From this analysis it appears that these cultures did not differ significantly in tenderness as observed by chewing. A significant seasonal effect was observed. Three factors may enter into such a seasonal effect. First, this observation may be due to true effect of season upon the tenderness of the kernel at canning stage; secondly, it may be due to personal bias in the testing of these samples from year to year; and third, it may be due to harvesting at a different stage of maturity in different years. Since moisture determinations by the Brown Duval oil tester were run on all cultures at time of harvest as a check on maturity in the 1931, 1932, and 1933 seasons, it was decided to determine if the stage of development at which the cultures were harvested differed from year to year. Standard deviations and coefficients of variability were calculated for 1931 and 1932, during which years a fairly large number of crosses were tested. The following results were obtained:

Year of test	No. of cultures tested	Moisture % at harvest		Coefficient of variability
		Mean	Range	
1931	21	68.17	67.3–70.2	1.54
1932	21	68.81	67.0–71.0	2.00

The coefficients of variability in 1931 and 1932 of 1.54 and 2.00%, respectively, are seen to be extremely low, indicating that these crosses were harvested at very nearly the same moisture content in all cases. It would appear from the data on moisture tests, therefore, that the seasonal variation observed in Table 4 was not the result of harvesting at different stages of maturity in different years. It is the author's conviction that the personal bias accounts in some measure for this observed seasonal effect. This, however, cannot account for the significant variation due to years observed in puncture tests shown in Table 3. Magoon and Culpepper (16) have found that seasonal variation plays an important part in tenderness of sweet corn.

It is probable, therefore, that there is a real seasonal effect even though cultures were harvested at very similar moisture content from year to year.

COMBINING ABILITY OF INBRED LINES FOR PUNCTURE TEST

From the work of Johnson and Hayes (13), Jenkins (11), and other investigators previously referred to, it is definitely known that high yielding inbred lines in general tend to produce high yielding crosses. It is of interest to determine the relationship, therefore, of inbred lines and crosses for the characteristic of tenderness in Golden Bantam sweet corn. This combining ability was studied (a) by correlating the average puncture index for the two years of test, 1929 and 1930, of the inbreds with their crosses; and (b) by correlating the puncture index of each cross with the average of all other crosses of both parents. In the latter case the study is that of the "tester" method in which the other 10 lines were used as testers to determine the reaction of the two lines in question. The correlation coefficients obtained are given in Table 5.

TABLE 5.—*Comparison of puncture index of inbred lines and the single cross yields for the purpose of measuring combining ability (av. 1929–1930).*

Characters correlated	n	Correlation coefficient
Puncture of cross with average puncture of the two parents	66	+0.252
Puncture of cross with puncture of high parent	66	+0.255
Puncture of cross with puncture of low parent	66	+0.180
Average puncture of all single crosses involving one parent with the puncture of the parent	12	+0.394
Puncture of cross with average of all other crosses of both parents	66	+0.720
5% point for N of 60		.2500
5% point for N of 12		.5324

Although the parent line-single cross correlations are low, they approach a significant level. The correlation of +0.720 for inbred lines in single crosses in comparison with all other crosses of two parents suggests the possibility of a considerable influence of parents on the progeny for the characteristic of tenderness.

In order to bring out the effect of parent lines on crosses more clearly, the 12 inbred lines were grouped into three groups: No. 1 the low puncture group (inbreds 38, 41, 42, 48), No. 2 the intermediate group (inbreds 44, 45, 47, 49), and No. 3 the high puncture group (inbreds 40, 43, 46, 50), for the purpose of determining into what classification the crosses would fall. In Table 6 is given the distribution of the single crosses for the various inbred groups crossed.

From this distribution it is evident that a fairly important inherited difference exists between inbred lines and that the characteristic which causes resistance to puncture is expressed in the progeny. From this study it appears that if the highest puncture group of inbred lines, i.e., the toughest, had been discarded by means of punc-

TABLE 6.—*Distribution of puncture tests of Golden Bantam single crosses made between inbred lines classified into three groups on the basis of their puncture test.*

Inbred groups crossed*	No. of crosses	Distribution of single cross puncture indices			
		299–323	324–348	349–373	374–398
Group 1 X group 1.	6	–	5	1	–
Group 1 X group 2 .	16	4	9	3	–
Group 1 X group 3. .	16	2	4	8	2
Group 2 X group 2. .	6	1	2	3	–
Group 2 X group 3 .	16	1	4	7	4
Group 3 X group 3 .	6	–	1	2	3
Total. . . .	66	8	25	24	9

	Average puncture, grams	% of crosses lower than average	Inbreds classified in group	Av. puncture in grams of inbreds in group
Group 1 X group 1 .	340	84.4	38, 41, 42, 48	323
Group 1 X group 2	337	81.3	———	——
Group 1 X group 3 .	346	37.5	———	——
Group 2 X group 2	346	50.0	44, 45, 47, 49	353
Group 2 X group 3.	356	31.3	———	—
Group 3 X group 3	371	16.6	40, 43, 46, 50	382
Total.	349			

*1 = Low puncture group; 2 = Intermediate puncture group; 3 = High puncture group.

ture tests, only 12 of the 33 crosses below the average for puncture would have been discarded. Had the tough group been discarded from the breeding work and the 8 remaining lines carried on, only 28 single crosses would have been made—a reduction in labor of crossing and testing of approximately 68%; whereas the loss of desirable hybrids would have only been 37%. It appears, therefore, that the use of the puncture machine on inbreds prior to their use in crosses is a suitable means of increasing efficiency of labor and of ensuring the greatest percentage of crosses which will have a low puncture index.

RELATION BETWEEN CERTAIN PLANT CHARACTERS AND PUNCTURE TEST

Since certain other plant characters were obtained on all of the 66 crosses tested, it was possible to determine whether these plant characters were related in any way to puncture index of the cultures. Accordingly, simple and partial correlation coefficients were calculated, using puncture index (1), date silking (2), yield of cut corn (3), and percentage of husk (4). The averages for the two-year period 1929–1930 for all crosses were used in this study. In Table 7 are given the correlation coefficients.

From the data obtained in 1929 and 1930 on these crosses, it would appear that the later silking hybrids tended to be more resistant to puncture than those of earlier silking date. The significant negative

partial correlation of puncture index and yield is hardly to be expected in this experiment due to the fact that toughness as well as yield increases with canning maturity. It seems that in these crosses the higher yielding hybrids possessed the least resistance to puncture when date of silking and percentage of husk was held constant. This general tendency was highly significant. Percentage of husk in this experiment was significantly correlated with puncture index when these two variables alone were considered. When date of silking and yield were held constant, this association becomes non-significant.

TABLE 7.—*Relation between plant and ear characters with puncture index of 66 single crosses of Golden Bantam grown for two years.*

Characters correlated	Simple correlation	Partial correlation
Puncture index (1) and date silk (2) ..	$r_{12} = +.4780$	$r_{12 \cdot 34} = +.4337$
Puncture index (1) and % husk (3) ...	$r_{13} = -.3010$	$r_{13 \cdot 24} = -.1803$
Puncture index (1) and yield (4)......	$r_{14} = -.1463$	$r_{14 \cdot 23} = -.3632$
Significant r, p .05	.2423	.2461
Significant r, p .01	.3150	.3198

DATE OF HARVEST IN RELATION TO RESISTANCE TO PUNCTURE AND PERCENTAGE MOISTURE AT HARVEST OF FOUR CULTURES OF GOLDEN BANTAM SWEET CORN

In order to study the relation of resistance to puncture and percentage moisture content in crosses of Golden Bantam sweet corn, three hybrids, 38 × 42, 38 × 49, and 77 × 78, and normal Golden Bantam, were planted for test in 1933. Eight single rows of each culture, 12 hills long, were planted in each of three replications, each culture being planted at random within each replicate. Eight harvests were obtained at different dates. The rows harvested at different dates were selected at random. All harvests were of three-stalk hills surrounded by corn as in previous tests, and each harvest sample was weighed with husks and after husking. Data also were taken of weight of cobs and of cut corn. Ten puncture determinations were made on each of four ears of each replicate. Duplicate moisture tests were made on a sample of cut corn from each replicate.

The analysis of variance of the data obtained is given in Table 8

TABLE 8.—*Analysis of variance and covariance of puncture index (x) and moisture percentage (y) on four cultures of Golden Bantam harvested at eight different dates in 1933.*

Variation due to	Degrees of freedom	Mean squares due to			
		X^2	XY	Y^2	r
Cultures	3	2180.897*	+95.09	25.247*	+0.41
Harvests........ ..	7	16627.060*	-1773.49	196.243*	−0.98*
Replicates....... ..	2	218.090	-13.21	.860	−0.93
Cultures × harvests	21	316.116	−31.29	7.283*	−0.66*
Error....... ..	62	250.132	−2.60	2.671	−0.10
Total..........	95				−0.81*

*Exceeds the 1% point.

and shows that there were highly significant differences between dates of harvest and cultures, both for puncture index and percentage of moisture.

The negative correlation between puncture tests and moisture percentage at different dates of harvest agrees with the findings of previous investigators on the relation of tenderness and maturity in canning corn. This coefficient (r—0.98) was extremely high and indicates that resistance to puncture and stage of maturity are very closely related. It may be said, therefore, that 96% ($r^2 = .9604$) of the variation in resistance to puncture in this test was directly ascribable to its inherent relationship with percentage of moisture at harvest.

The error correlation (r = —0.10) was non-significant. This correlation may be interpreted as a measure of the inherent association between resistance to puncture and percentage moisture of uniformity trial data. In a carefully controlled experiment this association would be expected to be non-significant.

It is of interest in this connection to compare the four cultures at different moisture levels for puncture test. Accordingly, correlation coefficients for puncture index and moisture percentage were calculated for each of these cultures. Coefficients of regression for puncture index and percentage of moisture were obtained also. These are given in Table 9.

TABLE 9.—*Coefficients of correlation (r) and regression coefficients (b) for puncture index and moisture percentage of four cultures of Golden Bantam sweet corn.*

Culture	r	b
38 x 42	−0.909	−0.094
38 x 49	−0.782	−0.105
77 x 78	−0.910	−0.116
Golden Bantam	−0.969	−0.087
5% point	.7067	
1% point	.8343	

Although the correlation coefficients were determined from the eight dates of harvest, an extremely low N value, nevertheless three coefficients exceeded the 1% level of significance and the fourth exceeded the 5% point. A comparison of the regression lines given in Fig. 1 is therefore of interest. Taking the canning maturity of all four cultures as 69% moisture, the puncture index of normal is 295 grams while that of 77 × 78 is slightly above 350 grams. This agrees with expectation. The method of Fisher (5) to compare regression curves was used with the regression lines of the three crosses and Golden Bantam to determine whether they were significantly different. Although the difference appeared to be relatively large, the t value obtained was 1.08, indicating that there was no significant difference between them.

STUDIES OF PERICARP THICKNESS IN RELATION TO PUNCTURE TEST AND MATURITY

In studying thickness of pericarp in two inbred lines of narrow grain Evergreen and the F_1 hybrid, Haddad (6) observed that after

an early stage of development the pericarp became thinner and increased in resistance to puncture with maturity. Since canned material of four cultures of Golden Bantam sweet corn were available on several different harvest dates, it was decided to determine if any difference in thickness of pericarp existed between cultures of this variety at different levels of maturity. Accordingly, four average kernels were selected from each culture harvested at two stages of development, a precanning and a post canning stage. Care was taken to select kernels typical of the average of all the material of each culture on hand. Strips of pericarp were cut from the crown of each kernel, washed in acetic acid alcohol solution, dehydrated in three concentrations of tertiary butyl alcohol (30%, 70%, and 100%), and imbedded in paraffin. Sections were cut 17.5 microns in thickness and stained with Delafield Haematoxylin. Measurements were made in

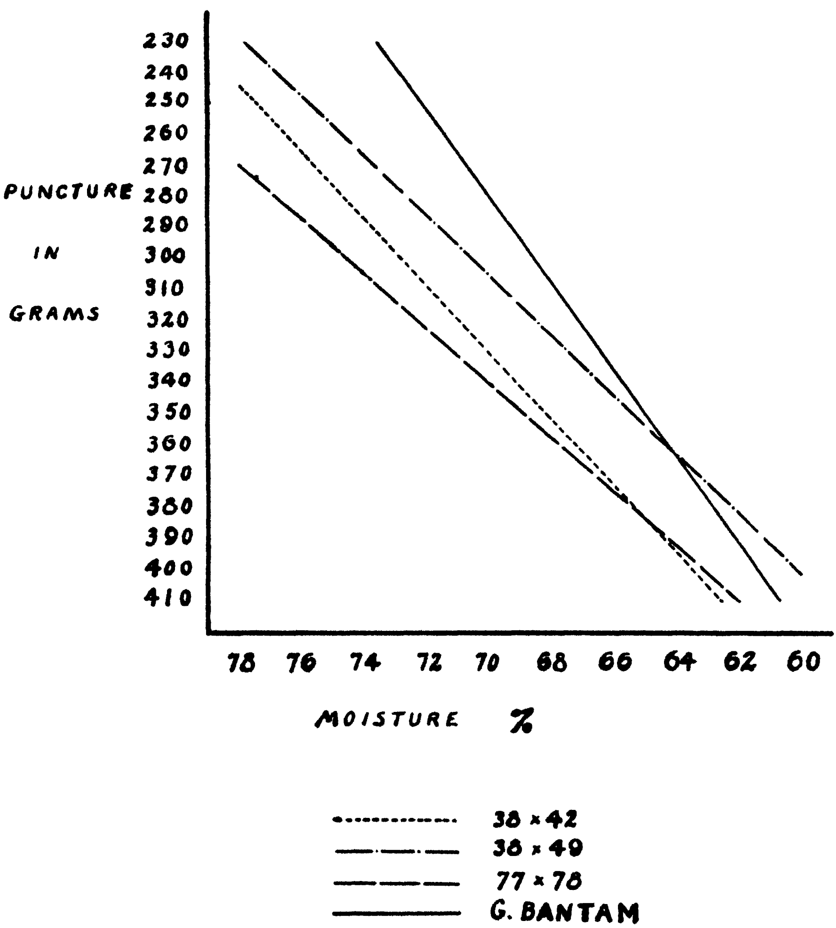

FIG. 1.—Regression lines of percentage moisture and puncture index of four cultures of Golden Bantam sweet corn, 1933.

millimeters using an ocular micrometer. From 6 to 9 measurements were made on all pericarp strips. In Table 10 is given the analysis of variance for the data obtained.

TABLE 10.—*Analysis of variance of pericarp thickness of four cultures of Golden Bantam at two dates of development (76 to 77% and 60 to 63.5% moisture).*

Variation due to	Degrees of freedom	Sum of squares	Mean squares	F
Cultures	3	.00146	.000487	.58
Maturity	1	.02398	.023980	28.75*
Cultures × maturity	3	.00265	.000883	1.06
Error	24	.02001	.000834	—
Total	31	.04810		

*Exceeds the 1% point.

From the preceding analysis it is evident that the only significant difference in this analysis was that caused by maturity of the samples. In all cases the samples of 60 to 63.5% moisture were slightly thinner than those of 76 to 77% moisture.

Since no culture effect was found, an average of all four cultures for each of the two maturity stages was obtained and compared with puncture index and percentage moisture at harvest. These are given in Table 11.

TABLE 11.—*Relation of percentage moisture, puncture index, and pericarp thickness in Golden Bantam sweet corn.*

Development stage	Average percentage of moisture	Puncture index, grams	Thickness of pericarp, mm
Precanning	76.6	277.9	.101
Post canning	61.9	380.4	.084
Number of determinations in each average	8	160	112

It appears, therefore, that in Golden Bantam sweet corn the same relationships of thickness of pericarp and toughness with different stages of development are found as has been reported by previous investigators (3, 6).

STUDIES OF SAMPLING METHODS IN RELATION TO A MORE ACCURATE USE OF THE PUNCTURE MACHINE

Although puncture tests may be made rapidly with the puncture machine used in this experiment, it is of great importance to determine the sampling methods which will increase the accuracy of the data obtained. The data obtained on normal Golden Bantam harvested at eight dates in 1933 was used for a study of sampling technic. In this culture 10 punctures were taken on each of four ears from each of three replicates at each of the eight dates of harvest. Thus, 960 puncture readings were obtained for this culture. The analysis of variance for these puncture readings is set up in Table 12.

TABLE 12.—*Analysis of variance of puncture tests on 96 ears of Golden Bantam sweet corn.*

Variation due to	Degrees of freedom	Sums of squares	Mean squares
Replicates	2	120.102	60.051
Dates	7	8888.162	1269.737
Ears	3	5520.504	1840.168
Replicates × dates	14	779.582	55.684
Ears × dates	21	1604.563	76.407
Error (a) between ears	48	3684.183	76.754
Total between ears	95	20597.096	
Error (b) within ears	864	3283.400	3.8002
Total	959	23880.496	

In this analysis two errors are obtained. Error (a) the variance of puncture between ears (76.754) contains the variation due to ears and also contains error (b), the variance of puncture within ears (3.8002). The obviously large variation due to ears in comparison with that within ears indicates immediately that greater precision could have been obtained in the experiment by increasing the number of ears taken, at the expense of the number of punctures per ear. Using the formula of Immer (10), $K = \frac{1}{N}\left(p + \frac{m}{n}\right)$ where K is the required variance, N the number of ears per plat, n the number of punctures per ear, m the variance between punctures, and p the estimated true variance between ears expressed on an ear basis, it is possible to determine the number of ears and the number of punctures per ear necessary to reduce the variance to any required level.

Substituting in the above formula, $K = \frac{1}{4}\left(\frac{7.2954}{1} + \frac{3.8002}{10}\right) = 1.92.$ If different values of N and n (number of ears and number of punctures per ear, respectively) are substituted, it is possible to show what value of K could have been obtained. Thus, eight ears sampled with five punctures per ear would reduce K to 1.01. If two ears with 20 punctures each were taken, K would increase to 3.74. It would appear, therefore, that if it is possible to take 40 punctures on each field replicate, the most accurate sampling system with a minimum of increase in labor would be to select eight ears and obtain five punctures per ear, i.e., increase the number of ears and reduce the number of punctures per ear.

DISCUSSION OF RESULTS

The data presented show that a puncture machine of the same principle as that used by Culpepper and Magoon (3) can be used satisfactorily for determining differences in tenderness between inbred lines and crosses as measured by resistance of kernel to puncture. Significant differences were obtained between crosses in this study. Probably the most difficult and the most important part of the

experimental work involved in comparing cultures is that of the determination of harvest date. The "thumb nail" test, together with date of silking and general ear characteristics, appeared to be a fairly satisfactory method of determining canning harvest date. The inter-annual correlation for puncture test, 1929–1930, of +0.4096 indicates that cultures tended to be somewhat similar in puncture index in both years. A comparison of this correlation with that of yield for these same crosses of +.0250 gives evidence that in Golden Bantam sweet corn the characteristic of tenderness is not any more difficult to study than that of yield.

The data obtained on chewing tests on 11 selected cultures over a period of five test years showed no significance between cultures, while puncture tests for the same cultures over the same years showed a very significant difference. It is evident, therefore, that grading corn into classes by chewing tests was not as accurate a method as that of the puncture machine for determining tenderness in this series of Golden Bantam cultures.

A pronounced seasonal difference for puncture index upon all cultures was observed in the five-year test of 11 cultures. Although this effect could have been obtained by harvesting all cultures at different stages of maturity in different years, it is believed that this factor was of minor importance. Percentage of moisture data on all cultures harvested in 1931 and 1932 indicate that cultures were harvested at very nearly the same stage of maturity in both seasons. Although cultures reacted differently in certain seasons, this interaction was of significantly less importance than that of cultures for all seasons. The interannual correlation coefficient (1929–30) for puncture on 60 crosses of +0.4096 previously discussed substantiates the observation that tenderness is a permanent feature of certain cultures of Golden Bantam sweet corn.

In all analyses made on the data obtained in these experiments on tenderness, no significant variation due to replication was observed. Although fairly uniform soil was obtained for test purposes in all years, a higher variation due to replication was expected. Apparently variation in soil had little effect upon resistance to puncture. Due to the extremely high negative relationship between percentage moisture and puncture test, it is quite apparent that any slight variation in maturity between replicates would cause most of the variation observed.

In the study of combining ability for resistance to puncture, the data indicate that the use of puncture indices for selecting inbreds to produce tender crosses is sound procedure in Golden Bantam sweet corn. Due to the large number of single crosses which it is possible to make from a comparatively few inbred lines, any selection for tenderness in inbred lines will greatly lessen the work of crossing and subsequent testing of crosses. Although no variety inbred crosses have been tested in comparison to inbreds themselves, it appears that testing of inbreds themselves for resistance to puncture is a fairly satisfactory method of selection.

In the study of the relation of moisture to puncture test the findings of previous investigators were corroborated. In the comparison of

four cultures harvested at different stages of development, differences of puncture at different moisture levels were observed. Regression coefficients of puncture index on percentage moisture at harvest on each of the four cultures harvested at different stages of maturity were obtained. Although the regression lines appear to be quite different (Fig. 1), there was found to be no significant difference between any of them. In spite of the fact that none of the regression coefficients differ significantly in this study, there is reason to believe that differences may exist between cultures of Golden Bantam for type of development.

Thickness of pericarp was studied on four cultures at two different stages of maturity. It was found that the pericarp was thicker at the precanning stage than at the post-canning stage for all cultures. No difference was observed between cultures for this character. Since Haddad (6) found differences in pericarp thickness at certain stages of development between two inbred lines of Narrow Grain Evergreen sweet corn, it is to be expected that such differences could be found in Golden Bantam.

In studies of tenderness as judged by puncture index, sampling methods must necessarily be used. Accordingly, a sampling technic study was run to determine the accuracy which could be obtained with the minimum of added effort. It was found that by doubling the number of ears punctured from each plat and taking half the number of punctures per ear, the accuracy of the puncture index was nearly doubled.

SUMMARY

1. By the use of the puncture machine described in this study, significant differences in tenderness were obtained at canning stage of maturity on 66 single crosses of Golden Bantam sweet corn as an average of two test years.

2. Chewing tests for tenderness of 11 selected cultures of Golden Bantam grown in five test seasons gave differences approaching significance. Puncture tests for tenderness on the same material showed highly significant differences.

3. Moisture tests were used in the later years of this experiment along with thumb nail tests, silking dates, and general ear characteristics for determining the exact canning stage in each culture.

4. Inbred lines showing low puncture indices tended to give crosses having a low puncture index. The parent-progeny correlation coefficients which were obtained indicated that tenderness was intermediate in F_1 crosses in comparison with the parents.

5. An interannual correlation for puncture indices of the years 1929 and 1930 on 60 crosses was higher but not significantly higher than the correlation for yield in the same crosses.

6. A seasonal difference in tenderness on 11 cultures of Golden Bantam in a five-year test was observed both by the puncture machine and by chewing tests. A pronounced difference due to cultures for the five-year period was observed also.

7. Puncture index in the data of harvest experiment was positively correlated with date of silking and negatively correlated with yield in

66 crosses grown for two test years. Percentage of husk appeared to have no relation to tenderness.

8. Stage of maturity as measured by percentage of moisture at harvest was negatively and very significantly correlated with puncture index for four cultures tested.

9. Resistance to puncture differed in four cultures of Golden Bantam during early stages of development of the kernels. Regression coefficients determined for puncture index and percentage moisture for the four cultures did not differ significantly, however.

10. In a study of pericarp thickness on four cultures of Golden Bantam, differences were observed between the precanning and postcanning stages of development for all cultures. No significant difference between cultures was observed.

11. In a study of sampling technic for purposes of increasing the accuracy of the collection of tenderness data with the puncture machine, it was found that when twice the number of ears were sampled with half the number of puncture tests taken on each ear, the accuracy of the test was almost doubled.

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THE INFLUENCE OF RATE OF SEEDING UPON CERTAIN PLANT CHARACTERS IN BARLEY[1]

J. W. THAYER, JR., and H. C. RATHER[2]

ACCORDING to results secured by other investigators,[3] the rate of seeding small grains has relatively little influence on yield but may materially influence the expression of certain plant characters such as tillering, number of heads per plant, length of head, etc. The purpose of the present study was to determine the differential response of certain barley varieties to different rates of seeding as indicated by variations in tillering, length of culm, length of head, number of kernels per head, weight of 1,000 kernels, weight of grain from 100 heads, and yield per acre.

MATERIALS AND METHODS

The varieties, chosen for these trials because they possess marked differences in the plant characters studied, included two two-rowed and two six-rowed barleys. Of the two-rowed barleys used, Spartan is a smooth-awned, early maturing variety and Michigan-Two-Row, a Hanna selection, is rough-awned and late in maturity. The six-rowed types were Glabron, smooth-awned and medium in maturity, and Wisconsin No. 38, a late-maturing barley also with smooth awns.

Planting was made with a 7-inch, 11-disc grain drill calibrated each year with each variety for each seeding rate. Four replications of each variety were planted in plats five drill-rows wide and 50 feet long, the seeding rates for each series of replications being ½, 1, 1½, 2, 2½, and 3 bushels per acre. Every fifth plat was drilled at 1½ bushels per acre to Spartan for the purpose of observation and for calculating yields.

As soon as the grain was well up, sections were marked off in the center row of each plat beginning 5 feet from the ends. These sectional rows were 10 feet long in the plats seeded at the ½ and 1 bushel rates, 5 feet long when rates were 1½ and 2 bushels, and 2½ feet long where seeding rates were 2½ and 3 bushels. Before tillering commenced, the number of plants in each of the marked sections was determined. These representative areas also furnished the material for all the plant determinations made later. Yield and other data likewise came from the center row of the five-row plats to eliminate the influence of varietal competition.

Enough plants were selected at random from each sample to give about 30 culm and head measurements when all developed culms and heads on a plant were used. A developed culm was any stem bearing a head with matured grain. Data were also recorded as to the number of plants per unit area and their respective numbers of developed and undeveloped culms. An undeveloped culm was taken as any stem or tiller over 15 cm long not bearing a head with mature grain, those less than 15 cm long being disregarded.

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[3]Reviews of literature and bibliographies are given by Bonnett, O. T., and Woodworth, C. M., in A Yield Analysis of Three Varieties of Barley, Jour. Amer. Soc. Agron., 23:311–326, 1931; and by Sprague, H. B., and Ferris, N. F., in The Effect of Uniformity of Spacing Seed on the Development and Yield of Barley, Jour. Amer. Soc. Agron., 23:515–533. 1931.

Calculations were made by standard machine practice and the standard errors were determined. In all of the tables, the weighted averages for the 3-year period, 1932–34, are given.

DISCUSSION OF RESULTS

STAND

In order to determine how closely field stands approximated expectations from a given seeding rate, a theoretical stand value based on laboratory determination of size of seed and its germinability was calculated. A comparison of the actual stand counts with these calculated values shows that the stands obtained in the field on the basis of 3-year averages, fell 10% below the corresponding calculated value. These average variations ranged from 84.4% for Glabron at the 2-bushel rate to 99.8% for Glabron at the ½ bushel rate, a variation due in a large part to "over" and "under" planting of the drill.

It is obvious from these data that field survival of plants was below stand expectations as indicated by laboratory germination. Seasonal conditions had a marked influence upon this plant survival, the low all-variety stand average being 87.6% in 1933 and the high 95.6% in 1932. With the exception that Wisconsin No. 38 barley gave a 3% poorer survival in the field, there were no differences between varieties in this respect.

The summary of plant counts per 10 feet of row for the different seeding rates, presented in Table 1, shows that in size of seed sowed the varieties ranked, from largest to smallest, Spartan, Michigan-Two-Row, Wisconsin No. 38, and Glabron.

TILLERING

That the varieties differed inherently in tillering is shown by the varietal variation in numbers of developed and undeveloped culms per plant (Tables 2 and 3). In general, all of the varieties tillered most in 1934, the season in which best yields were secured. There was a progressive decline in the numbers of developed and undeveloped culms as the rate of seeding was increased.

At the lower rates of seeding, Michigan-Two-Row tended to tiller more than Spartan, while the latter had more tillers at the higher rates. Both of these two-rowed barleys tillered more profusely than the two six-rowed varieties.

LENGTH OF CULM

There were only moderate differences between these four varieties in length of culm, although Spartan and Michigan-Two-Row tended to be just a little shorter than the other two varieties. At the same seeding rates, the maximum difference of the averages between the shortest and tallest varieties was only 6.2 cm.

As the rate of seeding was increased from ½ to 3 bushels to the acre, the length of straw decreased 4.3 cm or about 8% as an average for all varieties. The straw, although shorter at the heavier rates, was also finer and there was an increased tendency for the grain to lodge at the heavier seeding rates.

TABLE 1.—*Comparison of stand of barley varieties (number of plants per 10 feet of row) and percentage of perfection for each rate of seeding based on laboratory germination and size of seed, three-year average results.*

Variety	½ bu. No. plants	½ bu. Stand %	1 bu. No. plants	1 bu. Stand %	1½ bu. No. plants	1½ bu. Stand %
Spartan	38.2±2.2	98.7	71.8±2.7	92.8	104.2±2.9	89.8
Michigan-Two-Row	42.5±1.9	96.8	73.7±2.6	83.9	118.0±1.7	89.6
Wisc. No. 38	41.5±1.0	84.7	88.4±2.1	90.2	129.4±2.7	88.0
Glabron	48.9±2.6	99.8	86.9±3.0	88.7	141.0±4.8	95.9
Av. stand %		95.0		88.9		90.8

Variety	2 bu. No. plants	2 bu. Stand %	2½ bu. No. plants	2½ bu. Stand %	3 bu. No. plants	3 bu. Stand %
Spartan	137.4±2.4	88.8	171.2±5.9	88.5	210.8±7.2	90.8
Michigan-Two-Row	157.4±3.2	89.6	216.0±6.2	98.4	235.6±5.7	89.4
Wisc. No. 38	172.2±4.6	87.9	218.0±5.4	89.0	258.4±7.9	87.9
Glabron	165.4±6.2	84.4	223.2±6.4	91.1	265.6±6.9	90.3
Av. stand %		87.7		91.8		89.6

Actual number of plants per 10 feet of row at each seeding rate and percentage of theoretical perfect stand

TABLE 2.—*Number of fully developed culms per plant, three-year average.*

Variety	Rate of seeding ½ bu.	1 bu.	1½ bu.	2 bu.	2½ bu.	3 bu.
Michigan-Two-Row	2.22±.06	1.75±.03	1.29±.03	1.06±.02	0.97±.02	0.89±.02
Spartan	1.89±.04	1.56±.02	1.33±.02	1.16±.02	1.13±.02	0.92±.01
Wisc. No. 38	1.47±.03	1.04±.01	0.84±.01	0.81±.01	0.76±.01	0.79±.01
Glabron	1.40±.03	1.11±.02	0.89±.02	0.81±.01	0.84±.01	0.83±.01

TABLE 3.—*Number of undeveloped culms per plant, three-year average.*

Variety	Rate of seeding ½ bu.	1 bu.	1½ bu.	2 bu.	2½ bu.	3 bu.
Michigan-Two-Row	1.05±.03	0.80±.02	0.55±.02	0.49±.01	0.39±.01	0.32±.01
Spartan	0.92±.03	0.64±.02	0.53±.02	0.39±.01	0.37±.02	0.26±.01
Glabron	0.73±.03	0.47±.01	0.34±.01	0.34±.01	0.25±.01	0.23±.01
Wisc. No. 38	0.58±.02	0.38±.01	0.32±.01	0.26±.01	0.27±.01	0.20±.01

TABLE 4.—*Length of culm in centimeters, three-year average.*

Variety	Rate of seeding					
	½ bu.	1 bu.	1½ bu.	2 bu.	2½ bu.	3 bu.
Wisc. No. 38 ..	56.2±.38	58.7±.38	54.9±.33	56.1±.31	52.2±.37	52.1±.39
Glabron . .	56.5±.36	55.5±.39	54.8±.41	51.1±.39	51.2±.44	50.2±.47
Michigan-Two-Row.	52.7±.35	52.5±.33	52.3±.35	49.9±.34	49.3±.37	49.6±.39
Spartan	52.2±.38	53.8±.35	51.1±.35	52.4±.39	50.0±.40	48.5±.42

As is to be expected, seasonal variations in straw length were greater, running as high as 20 cm. Variations in soil fertility and general productive conditions, as has been so commonly observed, can induce extreme variations in this respect.

LENGTH OF HEAD

In general, the longest heads were produced by Michigan-Two-Row barley followed in order by Wisconsin No. 38, Spartan, and Glabron. This character also varied materially in the different seasons, but not in proportion to yield. At the 1½ bushel rate in 1932, for example, Wisconsin No. 38 barley heads averaged 7.51 cm long and the yield was 30.6 bushels per acre; in 1934, the heads were 5.51 cm long and the yield 39.7 bushels per acre; while in 1933, the heads were intermediate in length, 6.37 cm, but the yield was poorest of all, 23.7 bushels per acre. This same general relationship, or lack of relationship, between yield and length of head prevailed with all varieties.

TABLE 5.—*Length of head in centimeters, three-year average.*

Variety	Rate of seeding					
	½ bu.	1 bu.	1½ bu.	2 bu.	2½ bu.	3 bu.
Michigan-Two-Row	9.43±.09	8.45±.07	7.50±.07	6.99±.07	6.36±.07	6.01±.07
Wisc. No. 38 .	8.00±.08	7.43±.07	6.43±.07	5.91±.06	5.17±.06	4.58±.05
Spartan . .	7.23±.05	6.49±.05	5.91±.05	5.60±.05	5.17±.05	4.85±.07
Glabron	6.61±.06	5.87±.05	5.12±.05	4.71±.05	4.10±.04	3.87±.04

The length of head was materially reduced as the rate of seeding was increased. The general average decrease in head length from the ½- to the 3-bushel rate was 3 cm, or approximately 40%.

NUMBER OF KERNELS PER HEAD

The number of kernels per head was influenced most by head types, the six-row barleys having a much greater number of kernels per head than the two-row types. There was also inherent variation within these general types, Michigan-Two-Row always producing a greater number of kernels per head than Spartan and Wisconsin No. 38 a greater number than Glabron.

TABLE 6.—*Number of kernels per head, three-year average.*

Variety	Rate of seeding					
	½ bu.	1 bu.	1½ bu.	2 bu.	2½ bu.	3 bu.
Wisc. No. 38..	35.2±.30	34.9±.16	29.6±.19	27.4±.19	23.1±.06	18.2±.16
Glabron.	33.2±.14	29.5±.12	24.1±.07	21.8±.06	18.5±.04	16.5±.04
Michigan-Two-Row	19.5±.05	19.5±.04	17.4±.03	16.2±.06	14.7±.01	14.2±.03
Spartan ...	15.3±.02	14.3±.03	13.4±.04	12.7±.04	11.7±.05	11.5±.06

All varieties produced the greatest average number of kernels per head at the ½-bushel rate and the least at the 3-bushel rate. The two-row barleys were not as greatly affected in this respect by changes in rate of seeding as the six-row barleys, dropping only 25% as compared with 50% for the six-row types as the rate of seeding was increased from ½ to 3 bushels per acre.

Seasonal effects upon the number of kernels per head were similar to those on length of head in that the seasonal variation within varieties was not as great as the difference due to variety or rate of seeding.

WEIGHT OF 1,000 KERNELS

Spartan barley at all seeding rates produced significantly heavier kernels than any of the other varieties. Wisconsin No. 38 produced the lightest kernels and Michigan-Two-Row and Glabron fell between these extremes with Michigan-Two-Row slightly the heavier.

The weight per 1,000 kernels decreased for all varieties an average of 5.4 grams or approximately 14% as the rate of seeding was increased from ½ to 3 bushels per acre. This change, and the change due to seasonal variations was small in comparison with variations in tillering, length of head, and number of kernels per head. The fact that size of kernel is influenced to some extent by rate of seeding should be of interest to those desirous of producing an especially large or small kerneled grain of a given variety. Maltsters, in general, prefer the smaller kerneled grain provided it is of good weight per bushel.

TABLE 7.—*Weight of 1,000 kernels in grams, three-year average.*

Variety	Rate of seeding					
	½ bu.	1 bu.	1½ bu.	2 bu.	2½ bu.	3 bu.
Spartan.......	45.1±.49	44.4±.64	42.5±.61	42.5±.52	40.8±.63	40.3±.70
Michigan-Two-Row.	39.4±.44	39.2±.60	37.8±.53	36.8±.50	35.3±.65	33.9±.41
Glabron......	34.1±.34	33.0±.37	31.9±.36	30.8±.39	30.0±.43	28.7±.44
Wisc. No. 38 ..	33.5±.39	32.3±.40	30.2±.36	30.2±.30	27.8±.28	27.5±.34

YIELD

The yield of grain per acre as determined from harvest of the center row of each of the plats is presented in Table 8. One bushel per acre

proved an adequate rate of seeding for the six-rowed varieties, but not for the larger seeded two-rowed barleys despite their greater tillering. Spartan barley yielded best when seeded at 2½ bushels per acre, although the yield difference was not statistically significant for the 2, 2½, and 3 bushel rates. Michigan-Two-Row barley attained its maximum yield at 1½ bushels per acre, while Glabron and Wisconsin No. 38 showed no statistically significant variations in yield at seeding rates ranging from 1 to 2½ bushels per acre. In all cases, ½ bushel per acre was too light, and all varieties except Spartan tended to drop in yield when seeded at 3 bushels per acre.

TABLE 8.—*Yield in bushels per acre, three-year average.*

Variety	Rate of seeding					
	½ bu.	1 bu.	1½ bu.	2 bu.	2½ bu.	3 bu.
Glabron	25.5±1.2	27.2±1.2	29.3±1.3	27.9±1.3	29.4±1.3	28.3±1.3
Michigan-Two-Row	24.0±1.1	30.7±1.4	33.2±1.5	32.3±1.5	33.1±1.5	32.3±1.5
Wisc. No. 38	22.8±1.0	32.3±1.5	31.3±1.4	32.4±1.5	32.8±1.5	30.2±1.4
Spartan	16.9± .77	24.0±1.1	26.5±1.2	28.3±1.3	30.9±1.4	30.2±1.4

DISCUSSION

It is apparent from the results of trials that all varieties should not be seeded at the same rate because of inherent differences in tillering, size of seed, number of kernels per head and kernel weight. If Spartan and Wisconsin No. 38 barley are compared, using 1 bushel of seed per acre for each, Wisconsin No. 38 shows a yield advantage of 8.3 bushels per acre; if compared at 3 bushels per acre, the yields are identical; while if best yields of each are taken, Wisconsin No. 38 has a 1.9-bushel advantage, not statistically significant in these trials. This consideration is of concern not only to farmers, but also to experimenters in making comparisons between varieties markedly different in growth characteristics.

Although yields per acre varied materially in the different seasons, the optimum seeding rate for each variety fell within the same range each season, indicating that the seeding rate for a given variety is largely independent of soil and seasonal variations. There probably is an increasing tendency for poorer quality of grain as the seeding rate is increased at lower fertility levels.

When the optimum range in rate of seeding for a given variety has been determined, there is no apparent advantage in using more seed than is indicated by the lower limits of that range since the increase in seeding rate will be offset by decreases in tillering, kernel weight, and number of kernels per head. The productive capacity of a given variety is limited in any one season by soil and seasonal environment and more cannot be taken from that environment by attempting to crowd in more plants per unit area. Obviously a stand can be too thin, but the optimum rate of seeding, even at its lower limits, will take advantage of more favorable conditions of environ-

ment which may be presented by increases in tillering and those other components which finally make yield.

SUMMARY

Studies involving six rates of seeding were conducted with Spartan, Michigan-Two-Row, Glabron, and Wisconsin No. 38 barleys during the seasons of 1932 to 1934.

The number of plants per unit area increased, but tillering, length of culm, length of head, number of kernels per head, and weight of 1,000 kernels decreased as the rate of seeding was increased from ½ to 3 bushels per acre.

Because varieties differed in this rate of decrease for each character as well as in the characters themselves, there was some inherent difference in the optimum rate of seeding.

The rate of seeding which gave maximum acre yields was not a single rate, but a rather wide range. For Glabron and Wisconsin No. 38 barley it was from 1 to 2½ bushels per acre, for Michigan-Two-Row 1½ to 2½ and for Spartan 2 to 3 bushels per acre.

An increase in rate of seeding beyond this optimum range caused so great a reduction in growth characteristics, particularly tillering, length of head, and number of kernels per head that acre yields were reduced. There also was an increased tendency for the grain seeded at the heavier rates to lodge.

Growth factors were influenced markedly by seasonal environment, but the optimum rate of seeding, although varying somewhat with variety, appeared to be independent of environment.

SOIL LIMING INVESTIGATIONS: V. THE RELATION OF BORON DEFICIENCY TO OVER-LIMING INJURY[1]

JAMES A. NAFTEL[2]

DURING the course of liming investigations at the Alabama Agricultural Experiment Station, it has been found that injurious effects from excessive liming occurred with some crops on certain soils. In some instances only slight decreases in yields resulted while in others a virtual crop failure was obtained. Similar results have been reported by other investigators, but no satisfactory explanation has been given for the phenomenon. Reviews of the literature on over-liming have been given by Midgley (7)[3] and Pierre (11).

Since the problem of over-liming injury was of both practical and theoretical importance, a study was made in which several soil amendments were used in an effort to overcome the detrimental effect of over-liming. It is the purpose of this paper to report typical over-liming results on a light-textured soil, the effect of certain soil amendments, and especially the results of additions of small amounts of boron in overcoming and preventing over-liming injury.

PLAN OF INVESTIGATION

A Norfolk loamy sand was used for this study since it had been observed that plant growth was most seriously depressed in light-textured soils by excessive liming. The surface soil to plow depth was brought to the greenhouse, passed through a quarter-mesh screen, thoroughly mixed, and 8 kilograms of air-dry soil were placed in aged 2-gallon earthenware pots. The amounts of lime required to give various degrees of saturation were determined by the $CaCO_3$ equilibration method (8). Certain soil amendments were added to the cultures which were planted to different crops. The details and results of these studies are given below.

RESULTS

STUDIES WITH PHOSPHATE

Duplicate pots of soils unlimed and limed to 50, 100, and 150% saturation were set up with both C.P. $CaCO_3$ and a mixture of equivalent amounts of C.P. $CaCO_3$ and $MgCO_3$. The phosphate treatments were 0, 30, 60, and 120 pounds P_2O_5 per acre obtained from C.P. $NH_4H_2PO_4$. Moderate amounts of N and K were added uniformly to all cultures from C.P. salts. Vetch was grown as the first crop and the dry weights are shown in Fig. 1. It is evident from these results, which are typical of numerous studies made during the course of this investigation, that liming injury was obtained and that the added P did not overcome the injurious effect of lime. Both sources of lime gave similar results.

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[3]Reference by number is to "Literature Cited", p. 770.

Growth was retarded in the highly limed cultures at an early stage. The plants were abnormal in that the terminal bud died and little or no foliage developed. In later stages of growth numerous lateral shoots were produced. There was no noticeable chlorosis with this crop.

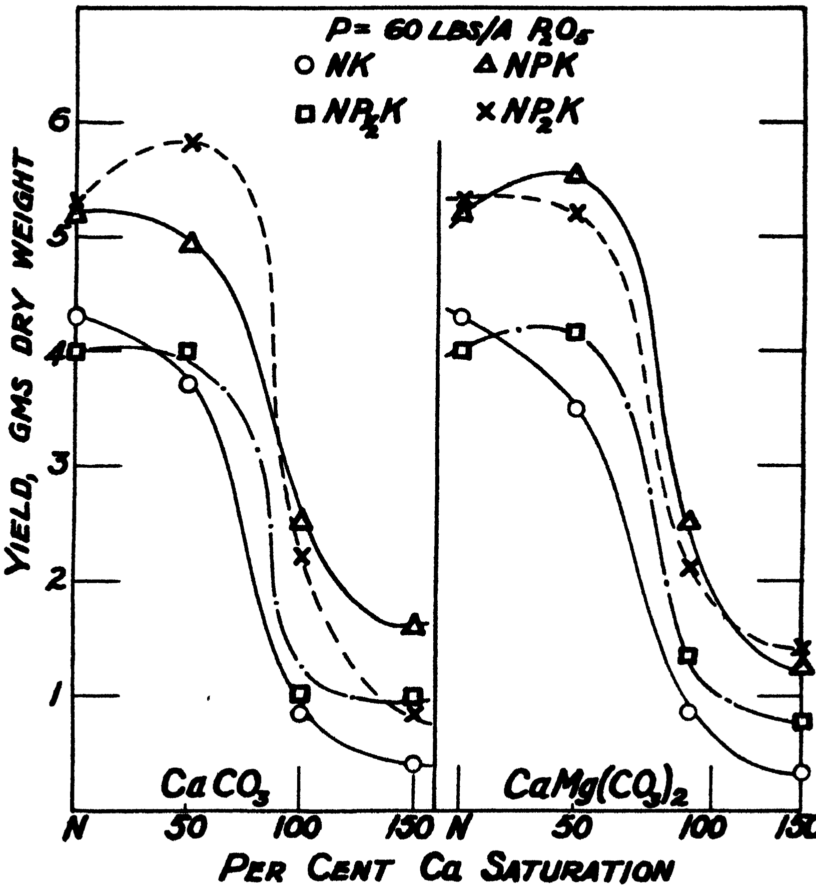

FIG. 1.—The effect of different amounts of phosphorus on over-liming injury to vetch.

Soil analyses at the time of harvesting the vetch are given in Table 1. The most serious injury occurred at 100 and 150% saturation where alkaline reactions were produced but where the water-soluble and readily available P were increased. This indicates that the unfavorable growth was not due to a lack of P. The depressed yields were, however, associated with large amounts of exchangeable Ca and low exchangeable Mn.

Soybeans were planted as the second crop on the same soils and fertilized with C.P. salts similarly to the first crop. The growth response to the increments of P as affected by lime was quite similar to that of the previous crop. This is shown in Fig. 2.

TABLE 1.—*Certain chemical constituents of a Norfolk loamy sand as affected by liming materials.*

% Ca-sorption capacity	M. E. per 100 grams	pH	Exchangeable Ca, m.e.	Exchangeable Mn, p.p.m.	NO_3-N, p.p.m.	H_2O soluble P, p.p.m.	Truog P, p.p.m.
			Unlimed Soil				
Native	0	4.88	0.80	0.97	8.1	1.15	8.8
			Limed with C.P. $CaCO_3$				
50	1.35	5.75	1.85	0.21	9 6	0.40	10.4
100	3 80	7.22	2.70	0.15	28.8	1.60	17.3
150	6.25	7.45	2.93	0.06	37.6	1.10	16.0
			Limed with C.P. Ca. $Mg(CO_3)_2$				
50	1.35	5 95	1 50	0 12	11.8	1.00	8.8
100	3.80	7.29	1.95	Tr.	37 6	2.60	16.0
150	6.25	7.70	2 69	Tr.	37.6	2.60	17.6

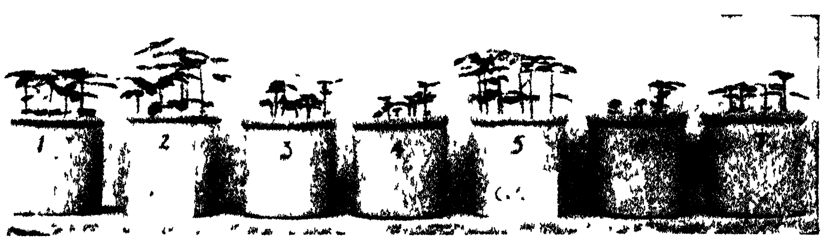

FIG. 2 Over-liming injury on Norfolk loamy sand as shown by soybeans. No 1 no lime, Nos 2, 3, and 4, increasing amounts of $CaCO_3$, Nos 5, 6, and 7, increasing amounts of Ca $Mg(CO_3)_2$

STUDIES WITH MANGANESE, CALCIUM SILICATE, AND BASIC SLAG

Cultures were set up with lime over the range of native, 50, 75, 100, and 150% saturation. A mixture of C.P. $CaCO_3$ and $MgCO_3$ was the source of lime where Mn was supplied to the soil at 25 and 100 pounds per acre and as a weekly spray application of 1% $MnSO_4$ solution. Basic slag and calcium silicate (T V. A. quenched) were added in amounts equivalent to the Ca and Mg required for the different degrees of saturation. Soybeans were grown with liberal amounts of N, P, and K fertilizers from C.P. salts except in the case of basic slag where the P was derived entirely from the material itself.

The injurious effect of the lime showed up early on all cultures at 100 and 150% saturation except those treated with basic slag. The appearance of the plants was similar to that discussed in the preceding studies. The yield curves are shown in Fig. 3 from which it may be seen that neither the $MnSO_4$ nor the calcium silicate used was of value in preventing the unfavorable results, while the basic slag was effective for this purpose. It is not evident why the latter material

was effective in preventing over-liming injury; however, besides furnishing Ca, Mg, and P, the basic slag contains numerous other elements. Soil reactions for the basic slag treatments were comparable with those of the other liming materials where injury occurred.

STUDIES WITH SOIL AMENDMENTS INCLUDING BORON

Since the previous studies indicated that over-liming injury was not due to unavailable P or Mn and did not occur at highly alkaline

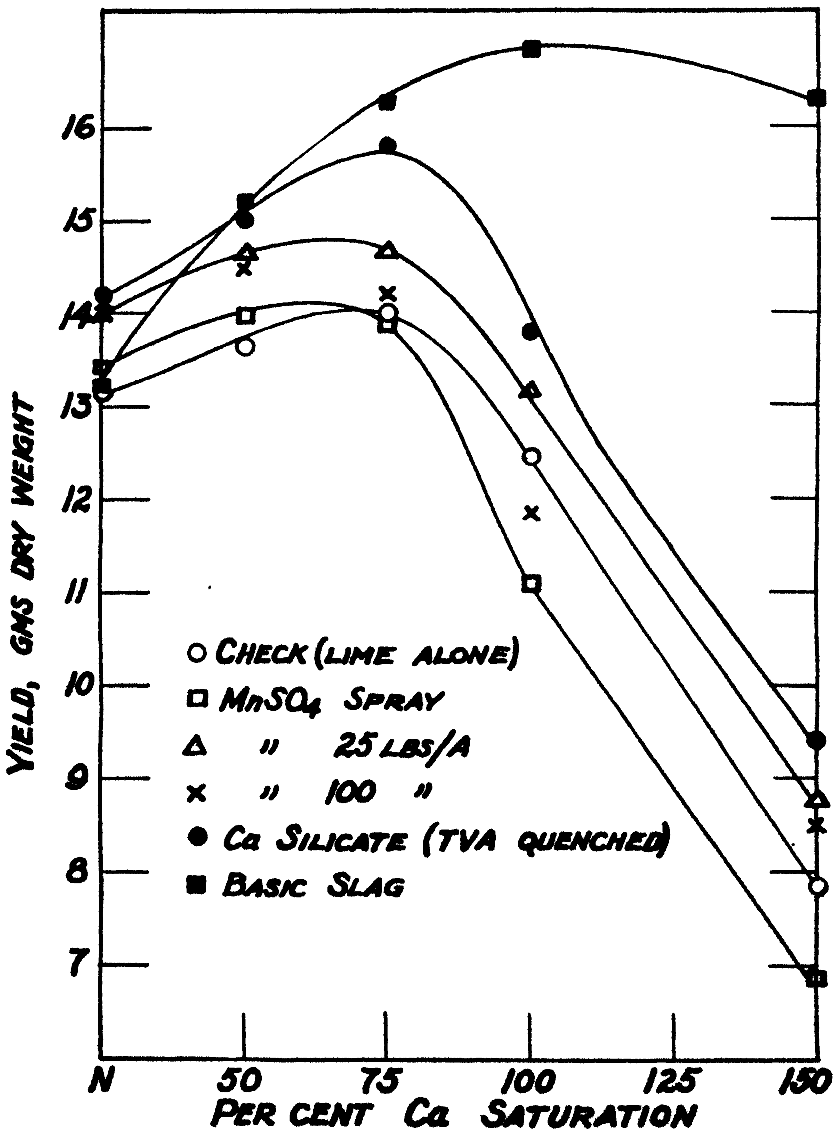

FIG. 3.—The effect of manganese sulfate, calcium silicate, and basic slag on over-liming injury to soybeans.

reactions when basic slag was present, additions of several micro-elements were made to the soils to determine if impurities in the basic slag might have been responsible for the failure to obtain over-liming injury with this material. Other studies included the addition of superphosphate (to note the effect of impurities), C.P. KCl, organic matter, calcium salts, and other materials to bring about changes in reaction of the soil. The source of lime was C.P. $CaCO_3$ which was added in increments up to 200% saturation. Vetch was the first crop grown on these soils.

TABLE 2.—*The yields of hairy vetch as influenced by lime and various soil amendments.*

Soil amendments		Yields in grams dry weight (average of duplicates) at percentage saturation with C.P. $CaCO_3$ of					
Series	Pounds per acre	Native	50	75	100	125	200
P-1	800 superphosphate	5.45	3.65	—	2.80	—	2.65
P-2	1,600 superphosphate	5.55	4.30	—	3.35	—	3.10
P-3	3,200 superphosphate	5.55	5.40	—	4.85	—	4.35
K-1	100 C.P. KCl	4.40	5.85	—	3.45	—	3.45
K-2	200 C.P. KCl	4.35	5.05	—	2.50	—	2.20
K-3	400 C.P. KCl	5.50	4.25	—	2.30	—	1.90
M-1	50 Fe and Mn	6.15	6.40	—	3.85	—	3.10
M-2	4 Fe and Mn (weekly)	5.60	5.60	—	3.40	—	4.00
M-3	2 H_3BO_3	6.50	7.70	—	7.65	—	7.86
M-4	200 sulfur	2.90	4.60	—	3.40	—	2.60
Ca-1	Check	4.90	6.75	4.90	4.20	3.30	2.25
Ca-2	$CaCl_2$*	—	4.35	4.30	3.80	—	0.70
Ca-3	$CaSO_4$*	—	4.35	4.25	4.55	—	5.10
H-1	$CaSiO_3$*	—	5.60	5.65	4.90	—	3.40
H-2	Na_2CO_3*	—	3.20	2.55	0.45	—	0.0
Ca-H	$CaCl_2+Na_2CO_3$*	3.70	4.15	5.65	6.25	—	—
OM-1	2,000 sugar	4.25	3.35	4.05	3.65	—	3.70
OM-2	10,000 soybeans	7.10	7.45	7.95	6.50	—	8.00

*No lime added, but the amendment was added in amounts equivalent to the lime added in the check (Ca-1).

Of the many trials made, only the amendments which included boron were effective in preventing over-liming injury. This is shown by the dry weights of vetch in Table 2. Boric acid was added to the soil in amounts equivalent to 1 p.p.m. B which completely prevented the detrimental effects of over-liming. This is clearly shown in Figs. 4 to 7. Note especially the plants shown in Fig. 5 where the plants from the unlimed soil, left, and from the over-limed soil, right, were removed from the soil to show the type of injury obtained without B. The plants on the right were short, brittle, and practically without foliage; apical necrosis had occurred; and they also had a very poorly developed root system with no root hairs or nodules. These results indicate that excessive liming brought about a deficiency of B to the plants in this soil.

Superphosphate at the highest rate, 3,200 pounds per acre, was slightly effective in reducing the over-liming injury. This might have been due to small amounts of B in this material. The addition of

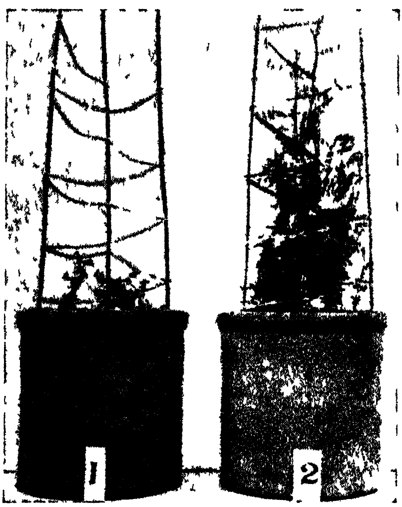

FIG. 4.—Soils limed to 200% saturation; No. 1, no boron added, and No. 2, 1 p.p.m. boron added. Vetch photographed when 1 month old

finely ground soybean hay brought about acid conditions and prevented the soil reaction from obtaining the point where over-liming injury occurs. The reactions of the soils from the different treatments are given in Table 3.

In another series, soil cultures were limed to the point where over-liming injury would occur and borax and boric acid (1 p.p.m. B) were added to study the effectiveness of B in preventing over-liming injury on various crops. The results with turnips, Austrian winter peas, and oats are given in Table 4. The most striking results were with turnips (Fig. 8) where the plants died in the soil limed to 150% saturation without B. Where B was added, the yield was increased over the unlimed soil. Liming injury was not severe on the peas; on the other hand, the additions of B burned the foliage of the plant. Slight liming injury was obtained with the oats which was completely overcome by the B additions. The B application burned the tips of the oat blades but was least evident on the highly limed soil. Results with tomatoes and cabbage were similar to those obtained for turnips. In all cases the injury was typical of the symptoms of boron deficiency.

TABLE 3.—*Reaction of soils after the vetch crop as influenced by various soil amendments and lime*

Soil amendments		Soil reaction (pH values) at percentage saturation with C.P. $CaCO_3$ of					
Series	Treatment in pounds per acre	Native	50	75	100	125	200
P-1	800 superphosphate	5.37	6.35	—	7.83	—	7.83
P-2	1,600 superphosphate	5.32	6.35	—	7.50	—	7.70
P-3	3,200 superphosphate	5.15	6.20	—	7.30	—	7.55
M-1	50 Fe and Mn	6.00	6.35	—	7.40	—	7.80
M-3	2 H_3BO_3	5.90	6.35	—	7.77	—	7.95
M-4	200 sulfur	4.70	5.80	—	7.05	—	7.75
Ca-1	Check	5.50	6.40	7.28	7.66	7.80	7.86
Ca-2	$CaCl_2$*	—	5.22	5.00	4.80	—	4.75
Ca-3	$CaSO_4$*	—	4.83	4.75	4.73	—	4.65
H-1	$CaSiO_3$*	—	6.75	6.95	7.30	—	8.40
H-2	Na_2CO_3*	—	6.20	6.00	6.85	—	6.85
OM-1	2,000 sugar	5.46	5.36	5.30	5.46	—	5.66
OM-2	10,000 soybeans	5.10	5.40	5.30	5.10	—	5.65

*No lime applied but amendment was added in amounts equivalent to the lime added in Check (Ca-1)

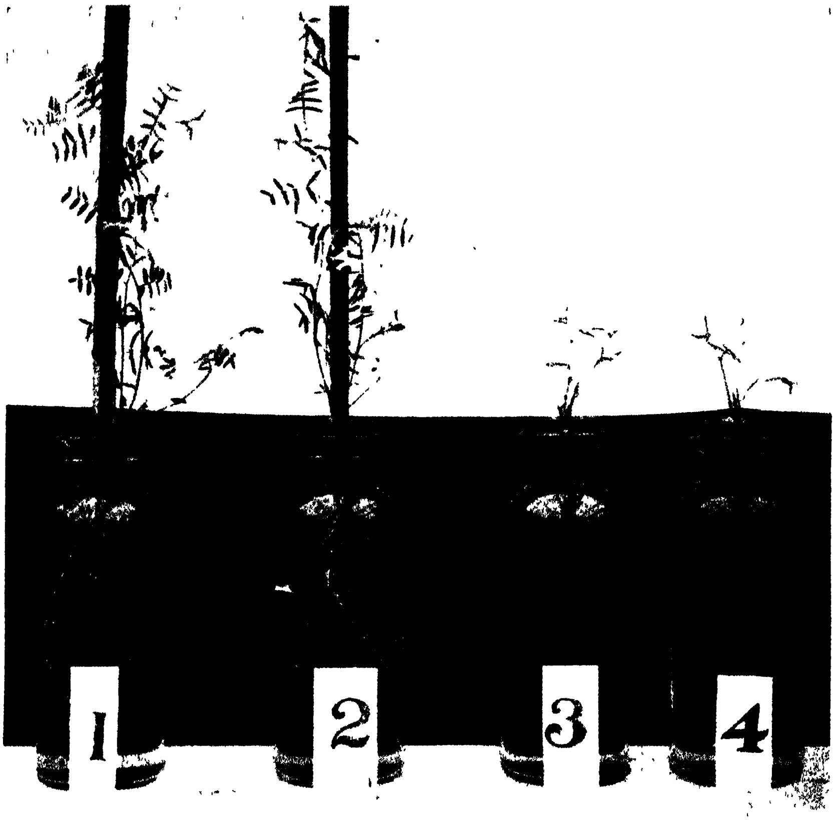

FIG. 5.—Vetch plants which were removed from the soil to show over-liming injury to tops and roots; Nos. 1 and 2 from unlimed soil, and Nos. 3 and 4 from soils limed to 200% saturation. (All without boron additions.)

DISCUSSION

That boron is essential for the normal growth of plants has been known since the investigations of Warrington (13,) Brenchley and Thornton (3), and Sommer and Sorokin (12), but the relationship of *soil liming* to *boron deficiency* was not suggested. Boron-deficiency symptoms have been observed in acid and neutral mediums (2) and on alkaline mediums (6). Even though boron deficiency was observed on calcareous soils or on soils which had been limed, little significance was attached to soil reaction. In fact, alkaline reactions were stated to be beneficial since the crops investigated, chiefly beets, grew best under these conditions. Ostwald (10) stated that there was no direct relation between boron deficiency and high lime content of soils. It is of interest in this connection that Neller (9) in a study of borax injury observed less injury on limed plats, but little importance was attached to the observation. McMurtrey (5) showed B deficiency

TABLE 4.—*Yields of turnips, Austrian winter peas, and oats as influenced by lime with and without boron.*

Boron added		Yields in grams at percentage saturation with $CaCO_3$ of		
Source	Lbs. per acre	Native	50	150
		Turnips		
0	—	11.1	6.4	0.0
Borax	17.5	11.0	11.3	12.2
		Austrian Winter Peas		
0	—	6.2	6.9	5.4
Borax	8.75	6.6	6.6	5.8
Borax	17.5	5.7	5.8	5.6
Boric acid	11.4	4.6	6.0	5.1
		Oats		
0	—	10.4	10.0	9.3
Borax	17.5	9.7	10.7	11.7

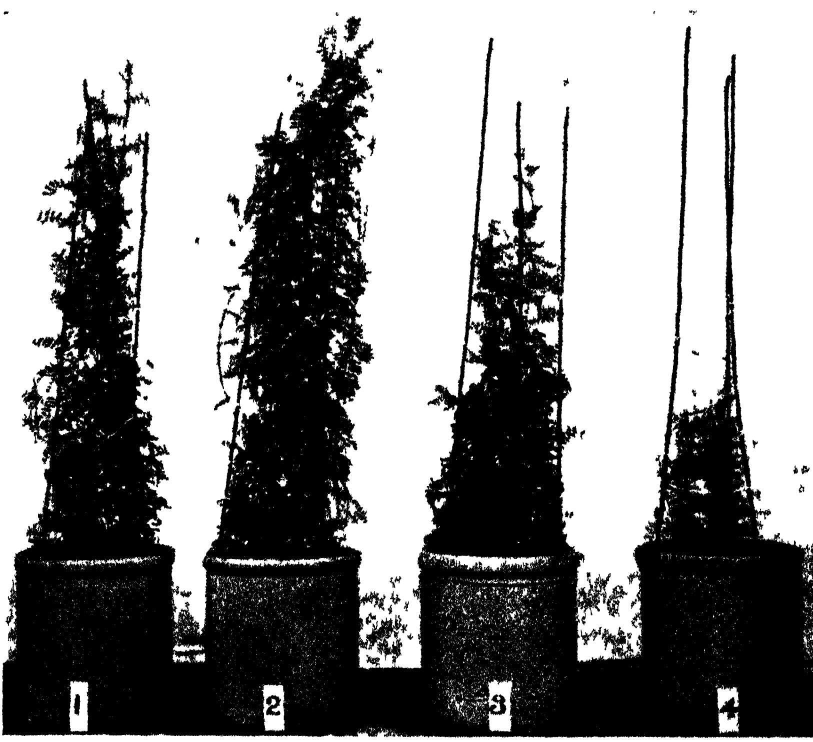

FIG. 6.—Over-liming injury on vetch; No. 1, no lime; No. 2, limed to 50%; No. 3 to 100%, and No. 4 to 200% saturation, respectively. No boron added.

was brought about in a field of tobacco grown on a light-textured soil where more or less pure fertilizer salts and Ca were used for several years. Apparently no significance was attached to the relation of Ca to the deficiency symptom nor were the amounts of Ca used mentioned in the report.

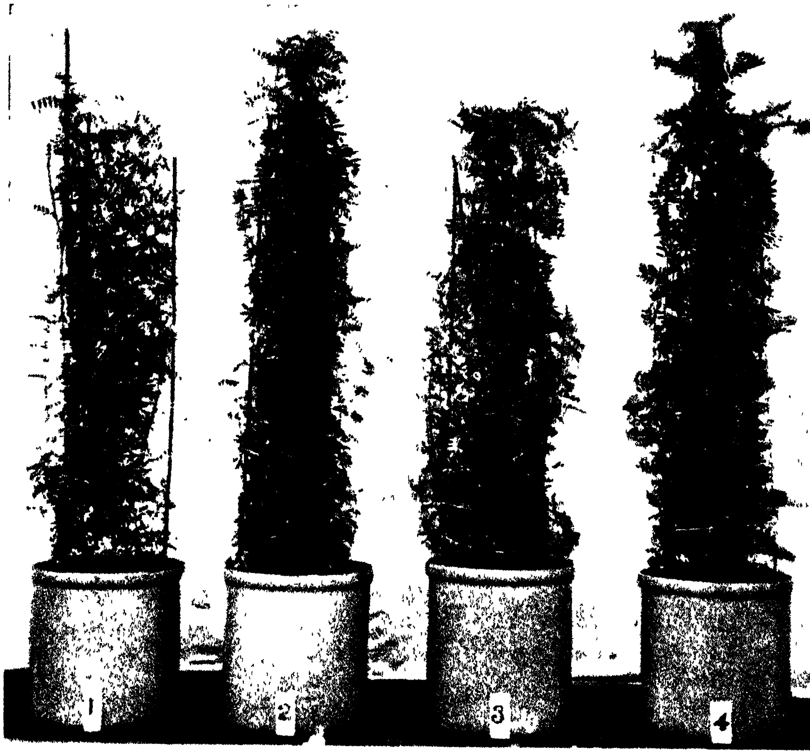

FIG. 7.—The influence of 1 p.p.m. boron in preventing over-liming injury. Soils limed similarly to those shown in Fig. 6.

FIG. 8.—Over-liming injury on turnips and the influence of boron in preventing injury. Nos. 1, 2, and 3 without boron, and Nos. 4, 5, and 6 with 1 p.p.m. B added; Nos. 1 and 4 unlimed, Nos. 2 and 5 limed to 50% saturation, and Nos. 3 and 6 limed to 150% saturation.

Apparently several of the Russian investigators (1, 4) have obtained results somewhat similar with boron in relation to over-liming as herein reported. Their investigations and the present investigations were carried out entirely independently and serve to prove the wide application of the results reported.

The mechanism involved in rendering boron unavailable when a soil is highly limed has not been explained. In preliminary studies in the laboratory and from the chemical reactions involved, it is untenable that insoluble borates are formed. Furthermore, from the consideration of the fact that over-liming injury does not occur on all soils and that when it does occur it is somewhat temporary, the explanation becomes more difficult. Evidence obtained recently indicates the possibility of the stimulation of bacterial activity, accompanying the liming of acid soils, to the point where there is competition between the micro-organisms and higher plants for nutrients present in small amounts. The latter explanation from theoretical considerations is plausible and is being investigated further.

SUMMARY

Excessive liming of a Norfolk loamy sand resulted in over-liming injury to vetch, turnips, oats, cabbage, tomatoes, and soybeans grown on the soil. In some cases a virtual crop failure resulted. The addition of large amounts of phosphorus, soil and plant applications of manganese, or soil amendments of calcium silicate did not overcome the injurious effect of excessive liming. Additions of basic slag, even where the soil was rendered quite alkaline, did not cause over-liming injury. The additions of micro-elements including boron to a soil otherwise over-limed completely prevented the injurious effect of over-liming.

It was concluded that over-liming on this light-textured soil was due to boron deficiency.

The mechanism involved in rendering boron unavailable to plants has not been explained. The possibility of precipitation of insoluble borates is discounted, but the possibility of biological absorption of boron by micro-organisms is pointed out.

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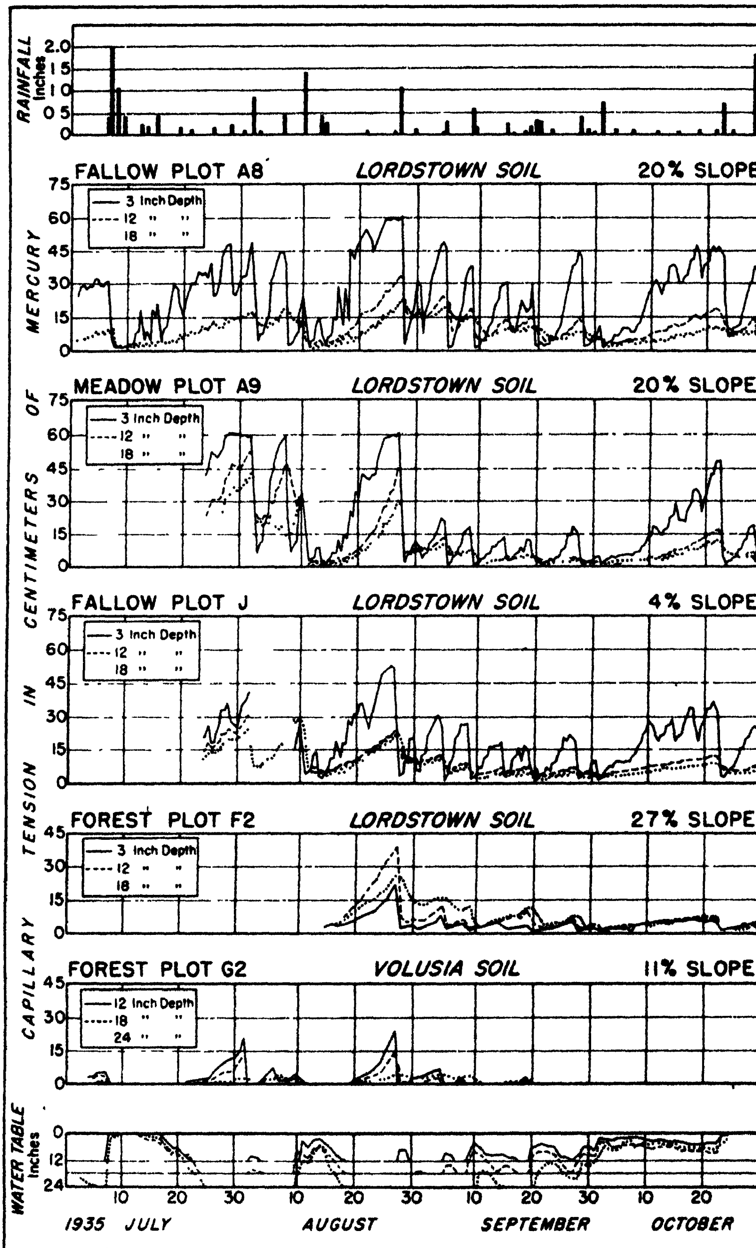

FIG. 1.—Records of the capillary tension during the summer of 1935 at three depths on four Lordstown soil plats and one Volusia soil plat. For the latter plat the depth of the free water table below the soil surface is also given. The rainfall during the same period is shown at the top of the figure.

pressures on the soil water greater than atmospheric pressure. These pressures were due to the presence of a free water table above the level of the cup. The location of the free water table as indicated at the various cups is given along the bottom of Fig. 1. Discrepancies among the data are probably accounted for by the friction head. Perched free water tables were shown to exist on August 2 and again during the first part of September. Run-off measurements are not available for the last two plats for the season of 1935.

Since the records of capillary tension on the various plats had such distinct variations, it was desirable to continue the readings during the summer of 1936 on the same plats. The cups were located within a few feet of where they were in 1935. Cups were placed at 3-, 10-, and 18-inch depths on all five plats. In contrast to the previous summer, which was unusually wet for New York State, the 1936 growing season was dry. For the six-week period beginning June 20, the rainfall was only 1.7 inches. When capillary tension exceeds the range of 1 atmosphere, porous clay apparatus cannot be used to measure it. Although installations had been completed by the end of June 1936, tensions at the shallower depths were beyond the range of the apparatus during most of July. However, after August 7 there was sufficient rainfall to make tension measurements possible during the remainder of the summer as shown in Fig. 2. A line missing from the figure indicates that either the cup or the system was leaking air and readings for that depth were not obtained. In general, tensions on all of the plats were greater than for the corresponding period of 1935.

During the period covered by Fig. 2, the rainfall was 10.3 inches. The fallow plat, A 8, lost 16.5% of this as run-off compared with a 0.4% loss from the meadow plat. The yield of hay for the entire season on the latter plat was 6,889 pounds per acre (dry weight). Considering the amount of water necessary to produce this large crop, one would expect the meadow plat to be the dryer of the two. At the 18-inch depth the tension readings show this to be the case, but at the surface layers tensions were so high on both plats that any contrast could not be observed. As in 1935, the fallow J plat again showed lower tensions than the fallow plat A 8.

On the Lordstown forest plat, F 2, where the run-off for the season was less than 0.1 inch, lower tensions were recorded than on either of the fallow plats. This would indicate that under the soil and slope conditions of this area the water lost as run-off from the fallow land plus that lost as evaporation from the surface was equivalent to the water requirements for a forest cover. Compared with the Lordstown forest plat the tensions on the Volusia forest plat were at times much higher. This rapid drying out is probably accounted for by the low water storage capacity of the Volusia soil. An appreciable amount of run-off occurred on this area August 20 and 22, but the upper soil was saturated after the rains, as indicated by both the appearance of seepage water and low tensions.

MOISTURE PERCENTAGE—CAPILLARY TENSION CURVES

In order to interpret the tension data in terms of a more commonly used index, experimental curves relating moisture percentage (based

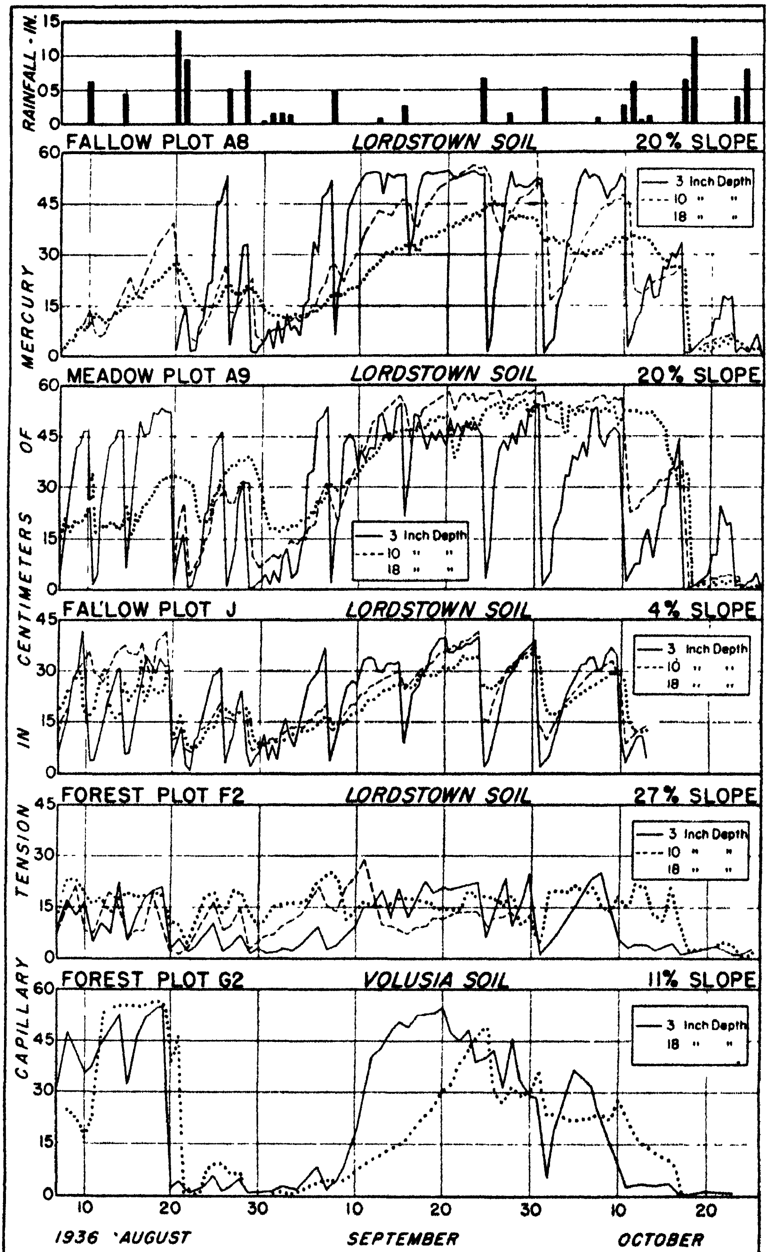

FIG. 2.—Capillary tension measurements obtained in 1936 on the same plats for which data are given in Fig. 1.

on the dry weight of the soil) and capillary tension were obtained for the Lordstown surface layer soil. Since temperature is a factor affecting this relation, the work was carried on in a room where the temperature was controlled at 24.8° C. Variations in temperature did not exceed 0.5°.

A 2.6-kilogram sample of Lordstown surface soil was oven dried at 100° C and placed in a commercially made double-walled auto-irrigator pot similar to those described by Richards and Blood (4). The weight of the pot without the soil was first determined. The tension on the water between the walls of the pot was controlled at various values and water would move into or out of the soil until at each value of the tension an equilibrium was established. The amount of water in the soil was determined by disconnecting the pot from the control system and weighing. A cover over the pot prevented evaporation, but a small opening in the cover maintained atmospheric pressure on the air surrounding the soil.

The results are shown by curve I, Fig. 3. The point indicated by the cross to the left of the curve is the amount of moisture absorbed by the soil after 10 days, starting from oven dryness, with the tension controlled at 13.5 cm of mercury. After 10 days the tension was reduced to 0 so the the soil became very wet (about 22%). The tension was then increased in steps up to 50 cm of mercury and back to 0. Equilibrium was established after each tension change. It was noted that as the soil dried out the points did not follow the same curve as during the wetting process. This is the hysteresis effect discussed by Haines (1) and Smith (6). The cycle from 0 tension to about 50 cm of mercury and back to 0 was carried through three times and smooth curves drawn, one for wetting and one for drying as indicated by the arrows. After the first wetting only one or two days were required for equilibrium to be established.

In an attempt to reproduce field conditions more accurately and to eliminate the effect on the soil of the initial oven drying, the curves were determined for a second sample. A relatively flat area in the field about 10 feet in diameter was spaded up and stones larger than 3 inches thrown out. A cup for measuring the tension was placed in the center of this area about 4 inches deep. The area was then covered to prevent evaporation. After several days the tension became constant at 8.2 cm of mercury. With as little disturbance of the soil as possible, a double-walled auto-irrigator pot was filled from the immediate neighborhood of the cup. At the same time four other samples, about 700 grams each, were taken. The average moisture percentage of these latter samples (20%) was assumed to be the initial moisture percentage of the soil in the pot. The cross plotted on curve II of Fig. 3 represents these field conditions. The tension on the water between the walls of the pot was controlled at the same value as the field tension for four days after sampling, and the moisture percentage increased about 0.9% as shown by the solid point. From this point on essentially the same process as before was repeated except that the soil was completely saturated at the low tension end of each cycle.

The shift in the location of curve II in relation to curve I was due chiefly to the elimination of the larger rocks from the second sample.

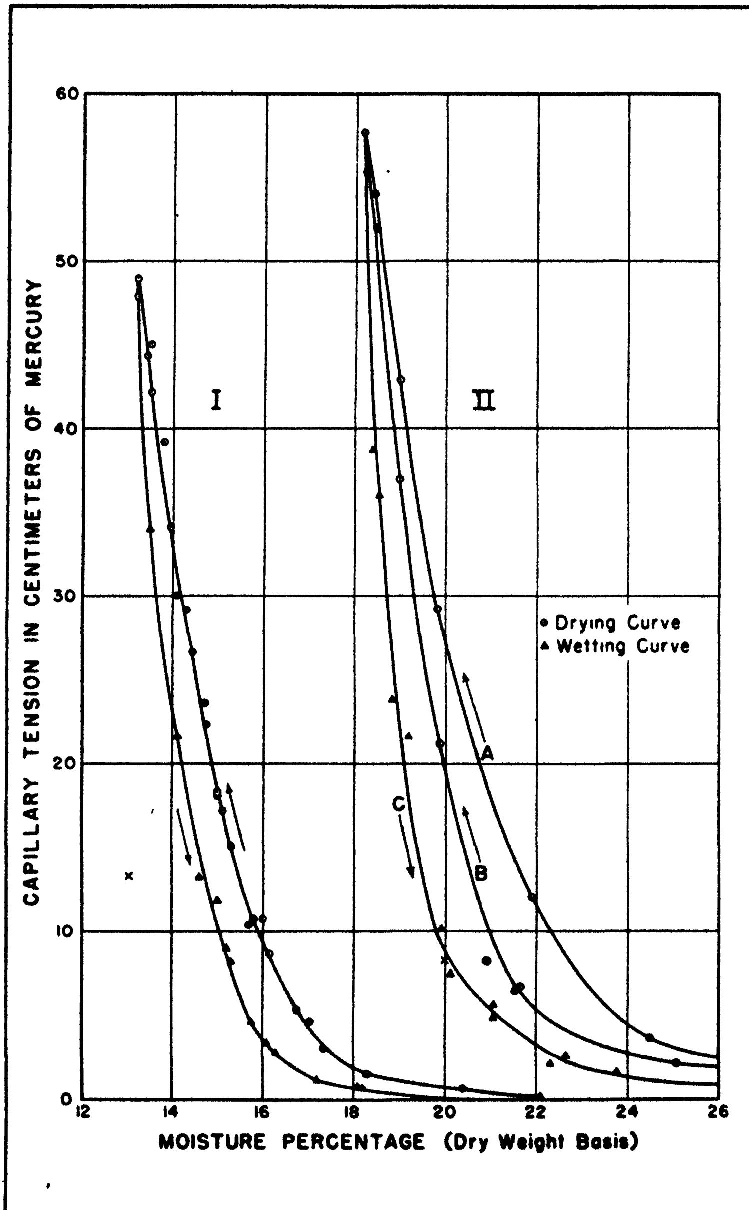

FIG. 3.—Curves relating moisture percentage and capillary tension for two samples of Lordstown soil. The arrows indicate the order in which the plotted points were obtained. Curve I is for an entire sample which was first oven dried. Curve II is for a sample with the larger rocks removed. The first drying curve after sampling is shown by A. On the second and subsequent dryings the points fell on the curve B. The wetting curve, C, remained the same each time.

In the case of this second sample it was found that the initial drying curve, A, was not the same as the second drying curve shown by B on Fig. 3. Subsequent dryings, after the second, followed B as well. That this variation was due to structural changes in the soil was shown by emptying the soil from the pot and putting it back with a disturbance comparable to the original sampling in the field. The first drying curve after disturbing the soil again differed from the second. Data for these latter curves are not shown on Fig. 3, since both were shifted a fraction of a per cent to the left of the ones drawn. The wetting curve, indicated by C, remained very nearly the same each time. The increase in moisture percentage above the field value when the tension was held the same is probably another effect of the change in structure at the time of sampling.

SUMMARY

Field measurements of capillary tension over parts of two growing seasons (1935 and 1936) are presented. Tensions were much higher during the comparatively dry summer of 1936. Relative values of capillary tension at various layers of the soil profile were consistent. Changes occurred where water was being lost or added before corresponding changes reached the other layers. The changes follow closely the precipitation data. Records of the capillary tension for two soils and for three crop relations on the same soil showed decided differences. These differences were maintained over the two summers.

Application is made of the same apparatus used in measuring capillary tension for observing variations in the level of the free water table.

Experimental curves relating moisture percentage and capillary tensions for samples of the Lordstown surface soil were found to differ, depending on whether the soil was drying or wetting. The drying curve was also changed when the soil structure was disturbed.

The use of capillary tension for expressing soil moisture conditions eliminates the uncertainties which are introduced by the hysteresis and structure effects when moisture percentage is used. Capillary tension has the additional advantage of applying equally well for stony soils. Tensions cannot be measured with porous clay apparatus when they exceed 1 atmosphere, but within the range of 1 atmosphere they are readily obtainable.

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THE SOLONETZ-LIKE SOILS IN SOUTHERN CALIFORNIA[1]

C. C. NIKIFOROFF[2]

MARBUT (6)[3] states that the "soils with heavy clay layers having all the morphological characteristics of Solonetz soil are of common occurrence along the coast of southern California. Their chemical characteristics have not yet been studied so it is not definitely known whether or not they are true Solonetz soils." More definite and detailed information regarding these soils is given by Storie (10) who states that "a number of California soils have the well-developed structural profile of the Solonetz. . . Those having the best developed Solonetz profile are the Huerhuero, Aliso, Stockpen, Merriam, Mouzerate, Antioch, Olivenhain, Las Flores, Tierra, Olcott, Solano, and Canby series. Approximately a half million acres of these soils have been mapped in California during the past four or five years; further soil survey will no doubt extend this acreage to a considerable extent."

A similar statement has been made by Kelley and Shaw (5) who report that "more than 450,000 acres of soils have been mapped having more or less definitely developed 'Solonetz' morphology", and also that "Kelley has reported on seven profiles, six of them having a very definite Solonetz, and one a semi-Solonetz morphology". The paper of Kelley (4) to which the last reference has been made is entitled, "The So-Called Solonetz Soils of California and Their Relation to Alkali Soils", which shows that the author was not at all sure that these soils are the true Solonetz.

It appears that these authors agree that many soils in southern California have a well-developed Solonetz morphology; none of them, however, affirms positively whether or not these soils are the true Solonetz.

A definition of the genetic type of any given soil requires a critical consideration of the morphology, chemistry, and genesis of this soil and their comparison with the norms established for this genetic type. It is assumed, however, that a strictly pedological morphology of any normally developed soil is a direct result of its own chemistry. Therefore, very often a sufficiently accurate correlation is based on soil morphology alone, provided that the latter represents a true pedogenic development.

A strictly pedological or genetical morphology refers to a harmonious development of the soil horizons. It is an "acquired" morphology that may be contrasted with the one "inherited" from the original parent material. The parent material consists not infrequently of several different layers. A fundamental distinction between the normal genetic soil horizons and the mechanical layers of parent material is that the former develop simultaneously, so to say collectively, through a common soil-forming process, whereas the latter

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture. Received for publication June 15, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 796.

are mechanically deposited one above the other, each in different periods of time, by different agencies and usually from different sources. If such mechanical layers are so thin that the soil-forming influences embrace a series of different layers, then it may happen that the different horizons develop from the materials different in physical or chemical composition and in origin. The mechanical layers of parent material naturally impose upon the soil profile a morphology and chemistry of their own that may obscure or even conceal entirely the properties evolving through the operation of the pedogenic process.

Only the acquired morphology represents the true genetic soil horizons and reflects a definite chemistry of the soil formation. A casual, mechanically arranged morphology may resemble that of the normally developed genetic profile, but, of course, it is not accompanied by the normally developed chemistry characteristic to the latter.

Because of a rather confusing and in some instances even conflicting interpretation of the term Solonetz by different authors, it seems necessary to review briefly the established physical, chemical, and genetic norms of this type before attempting to pass judgment as to whether or not the corresponding properties of the California soils fit these norms.

WHAT IS A SOLONETZ SOIL?

DISTRIBUTION

So far as it is known, the term Solonetz connotes a certain normally developed intrazonal soil associated with Chernozem, Chestnut, and Brown soil types. As applied to the Solonetz, the term "intrazonal" connotes a sporadic occurrence of this soil in spots within the zones occupied by different soils. On the other hand, however, an occurrence of the Solonetz only within certain climatic provinces suggests that an area of its distribution has a zonal character in itself and that its formation is associated with a particular complex of natural conditions. The broad zone of an intrazonal occurrence of the Solonetz embraces the zones of the grassland types of soil formation. So far only one case of its occurrence outside of this zone has been established, namely, in the Podzolic zone in East Siberia. This geographical anomaly has not been explained satisfactorily.

The Solonetz soils do not cover continuously any large areas but occur typically in small spots scattered through the areas occupied by the other soils. This intricate combination of the two or more different zonal and intrazonal soils is called a soil complex. The term "complex" denotes a certain pattern in which its components divide among themselves the surafce area. In some particular Chernozem-Solonetz, and especially the Burozem-Solonetz, complexes a part of the area occupied by the spots of Solonetz may be as much as one-half of the total area of the complex. Not many individual Solonetz spots are more than a few rods in diameter.

The striking peculiarity of the Solonetz soil is that it is an unsaturated soil, acid in the A horizon, and apparently developed

through strong leaching. In these respects it stands out in sharp contrast to all other soils with which it is closely associated. These are the typical saturated, neutral, or slightly alkaline, and unleached soils.

MORPHOLOGY

The principal physical characteristic of the Solonetz is its B horizon. This varies in thickness from about 5 or 6 inches to more than 2 feet. It is characterized by an exceedingly dense or compact consistency that becomes sticky and watertight in a moist soil and very hard in a dry condition. The color of this horizon is always darker than that of any other horizon in the profile. It may be black, brown, drab gray, or olive gray. The upper part of the horizon (about one-third of it) has typically the darkest coloring that grades without any sharp changes into the colors of the parent material. The texture of the B horizon is always heavier than that of parent material, and especially of the A horizon. On drying the B horizon of the Solonetz breaks into coarse, angular, firm clods which in the top section of the horizon appear not infrequently in the shape of rough angular prisms whose vertical axis is two to four times that of the horizontal axis. The latter varies from less than 1 inch to more than 3 inches. Not infrequently these prisms or columns are characterized by well-rounded biscuitlike tops. The vertical cracks that separate the prisms become more irregular in the middle and lower part of the horizon thus breaking the soil into the roughly cuboidal, coarse lumps having vertical and horizontal axes more or less equal. The prisms and clods, as well as the pores penetrating them, very often are coated with dark shiny films.

Some authors apparently assume that the so-called columnar or prismatic structure of the B horizon is the principal characteristic of the Solonetz soil and is in itself an indicator of the Solonetz formation, which never has been proved. Naturally a conspicuous columnar or prismatic structure in the upper part of the B horizon is an essential characteristic of one particular variety of the Solonetz soils that is designated accordingly as the columnar or prismatic Solonetz. Besides these there are known to be other groups of Solonetz soils which do not have this structure. The B horizon of these may have a lumpy, cloddy, nutlike, blocky structure or have no structure of any kind (massive).

It is not yet definitely known what causes the development of prismatic or columnar structure. Possibly it is a property of certain soil materials, especially of certain clays, to crack into miniature basaltlike vertical fragments due to shrinkage on drying under certain conditions. The latter refers especially to the condition in which the surface of the clayey horizon is covered by a relatively thin and loose A horizon. It is true that so far a columnar structure with well-rounded tops hardly ever has been found in any soil other than columnar Solonetz. Nevertheless it is also true that a vertical cracking of the B horizon that breaks it into roughly shaped prisms is not uncommon in many other soils.

The A horizon of Solonètz varies in thickness from less than 1 inch

to about 1 foot although rather seldom it is less than 3 or more than 10 inches thick; in the still rarer instances its thickness exceeds 1 foot.

As compared with the B horizon the A horizon has typically a lighter color, a coarser texture, and a more mellow or friable consistency all of which are especially pronounced in the lower part of the A horizon, which is commonly recognized as the A_2 subhorizon. The latter usually has a very light ash-gray color and very often is characterized by a fine laminated structure, not infrequently spoken of as "foliated". The individual platelets are too thin and delicate to allow their separation one by one without destruction, but a careful examination of the soil sample clearly shows that the flat aggregates are darker on the lower than on the upper side in their natural position in the soil.

This structure is not necessarily present in the A_2 subhorizon of every Solonetz, but it has been observed here so much more often than not that it has been recognized as one of the commonest features of the true Solonetz. The causes of its development and naturally its significance are not yet definitely known, though it is almost certain that this particular structure is a peculiar characteristic of the strongly leached horizons of the relatively heavy soils. In soils like the Podzol, degraded Chernozem, or Solonetz, it occurs typically in the A_2 subhorizon and has not been observed in any other horizon. It occurs also in the A horizon of certain semi-desert soils.

The boundary that separates the A and B horizons of the Solonetz is typically rather abrupt.

CHEMISTRY

Despite many careful investigations made by Gedroiz, Hissink, Kelley, de Zigmond, and others, the chemical nature of Solonetz is not completely known. Most investigators did not analyze the Solonetz profile as such, but have worked with soil materials of various origin and on various problems. Some were interested in the studies of the base-exchange phenomenon in the soil; others in the general investigation of soil alkalinity, its causes and methods of amelioration; still others in a study of the chemical behavior of the soil colloids, but not primarily in finding out the chemistry of Solonetz formation.

Gedroiz found that a saturation of the soil colloidal complex with exchangeable sodium produces certain physical properties similar to those characteristic of the B horizon of the Solonetz. His findings remarkably coincided with similar results reported independently by other soil chemists. From this a definition of the Solonetz as a soil containing exchangeable sodium among the other absorbed bases has been developed by Gedroiz and de Zigmond. Gedroiz especially emphasized the rôle of the monovalent cations among the exchangeable bases in the process of development of the specific physical properties of the Solonetz soil and contrasted the latter with the Chernozem whose absorbing colloidal complex is saturated almost completely by the divalent cations.

Kelley's (4) analyses of the seven profiles of the so-called Solonetz soils of California show that "magnesium is the dominant replaceable

base of the B horizon of all but one of these profiles". Kelley points out that "the rôle of replaceable magnesium in the development of Solonetz morphology has not been extensively studied. It is well-established, however, that magnesium clays are more colloidal than calcium clays."

Rost (8), who studied six profiles of the Solonetz from the Red River Valley in Minnesota, found that in all "six profiles both exchangeable Na and K are present in very small amounts and in the present stage of development appear to be relatively unimportant. Exchangeable Mg, on the other hand, is present in a relatively large amount and is the most prominent ion of the absorptive complex."

A similar result was reported by Ellis and Caldwell (2) from Manitoba. Shawryguin (9) sums up his study of the influence of the absorbed magnesium upon the physical properties of the soil in the following statement: "The absorbed magnesium changes the physical properties of the soil in the same way as the absorbed sodium does, however, in a considerably smaller degree. Therefore, the absorbed magnesium apparently can cause the development of solonetz characteristics if these are determined by the certain physical properties. . . ."

Rosov (7) in a resumé of his work also states that, "A solonetz morphology, chiefly characterized by the presence of the compact illuvial B horizon, does not agree precisely with the chemical data. In some instances a considerable quantity of the absorbed sodium can be found in a morphologically underdeveloped Solonetz, and vice versa some morphologically strongly developed Solonetz contain but a small quantity of the absorbed sodium." Considering the possible causes of such discomformity, Rosov points out that the typical illuvial horizon and a morphologically mature profile of the Solonetz can be developed even in the absence of the absorbed sodium.

These works point to a possibility that Gedroiz's definition of the Solonetz "as a soil whose absorption complex is more or less saturated with sodium" (after Kelley) is rather too rigid and narrow. It does not cover the entire group of the morphologically similar soils. This definition may be correct in regard to a certain group of the Solonetz but apparently it cannot be applied to the entire class of these soils.

It is generally known that the parent material of the Solonetz is in most instances impregnated by large quantities of different salts, among which the carbonates and sulfates of the alkali and alkali earth bases are by far the most common and form very often rather rich efflorescences. The A and B horizons (the latter usually in its upper part only) are typically free from any abnormal content of soluble salts and the former usually has a moderately to slightly acid reaction.

A content of humus in the solum of Solonetz is considerably less than that of the associated nonsolonized soils. It is assumed that the organic colloids are highly deflocculated in the Solonetz soil because of their saturation by an exchangeable sodium, and that this makes them unstable as regards decomposition and leaching. It should be remembered, however, that due to their conspicuous unproductivity the Solonetz soils do not bear even approximately as rich a vegetation as the surrounding nonsolonized soils do. Therefore, the amount

of organic residues and general biopedogenic turnover on these soils are never equal to those of the associated soils, and this may be responsible, at least in part, for an originally low content of humus independently from leaching. On the other hand, it is established that organic and mineral colloids actually undergo a shifting by leaching and a coagulation and fixation in the illuvial B horizon.

GENESIS

The complex forming distribution of the Solonetz makes it impossible to credit their formation to the local variety of the climatic or microclimatic conditions. The climate of the entire zone of occurrence of the Solonetz is not of the type promoting leaching, as shown by the zonal types of soil formation. This fact forced a search for the factors other than climate that stimulate the Solonetz development. A striking unproductivity of the Solonetz and a conspicuous difference of the native vegetation on the spots of Solonetz and on the surrounding nonsolonized soils naturally turned attention to a probability of some unevenly distributed and harmful for vegetation chemical factor that may be responsible for a Solonetz formation. Finally, on this ground, a hypothesis regarding the evolution of the Solonetz has been developed mainly by Gedroiz and de Zigmond. This hypothesis brings up a long-suspected genetic relationship between the Solonetz and other intrazonal soils of the steppe, such as Solonchaks and Solodis.

This evolution, as it has been expounded by Gedroiz and de Zigmond, proceeds consecutively through a process of replacement of salinization by the sodium salts; desalinization and alkalization which may be designated collectively as a solonization; and solodization or degradation of the Solonetz.

The three distinct soil types—sodium Solonchak, Solonetz, and Solodi—are regarded as stages in a continuous development that are connected by intermediate phases so that no sharp breaks separate them from each other. According to this theory the Solonetz is a product of desalinization of the sodium Solonchak— a process that is accompanied by an acquisition of certain physical properties caused by a sodium saturation of the soil colloids. Gedroiz holds that Solonetz is a very unstable formation and undergoes gradual degradation or regeneration into the Solodi. According to him, a development of the leached A_2 horizon is already an evidence of solodization so that the normal Solonetz apparently are supposed not to have this horizon at all.

This hypothesis has been received in soil science rather enthusiastically, although it has never been proved positively that a Solonetz formation is *always* a result of desalinization of the sodium Solonchak, nor that every Solonetz inevitably degrades into Solodi unless the process of evolution is turned backward toward the Solonchak stage.

To the contrary, several conditions hardly agree with this hypothesis. One of the most important among these is this: According to Gedroiz's and de Zigmond's views the sodium Solonchak, Solonetz,

and Solodi, representing the three principal stages of evolution, replace each other in time; one evolves from the other and passes into the third. Therefore, one should assume that any area presently occupied by any soil representing this or that stage of evolution has been or could be occupied in the past and can be occupied in the future by other soils representing the earlier or later stages of the same evolution, respectively. It naturally would follow that none of these types of soil can occur in some particular habitat in which the other types cannot be developed.

Such an assumption does not agree with the commonly known facts. The true Solodi is a typical soil of depressions. In the steppe it occupies areas that are topographically similar to those in the humid zones occupied by the hydromorphic Bog and Half-Bog soils. The Solodi is often associated with the Solonetz. The latter in such associations is found typically on tracts more elevated than those occupied by Solodi. Solonetz occurs typically in complexes with other soils like Chernozem, Chestnut, or Brown. Neither Solonchak nor Solodi form similar complexes. The most typical Solonetz is found not infrequently in such locations where neither Solonchak nor, and especially, Solodi were ever found.

These facts suggest that the Solonchak, Solonetz, and Solodi may be in reality genetically independent soil formations, whose development and distribution are controlled by different local factors in each case. This conclusion, however, does not exclude the possibility of an occasional metamorphosis of one of these soils into the other if the habitat has undergone the corresponding changes.

Another fact that disagrees with the Gedroiz-de Zigmond hypothesis is the existence of morphologically similar Solonetz soils containing very little, if any, sodium and nearly saturated by magnesium as shown by the latest chemical studies. Therefore, it still remains not definitely known whether the Gedroiz-de Zigmond hypothesis explains the origin and evolution of the Solonetz correctly and whether such an evolution actually occurs in nature.

Whatsoever causes may be, it is almost certain that the general profile of Solonetz develops because of leaching. The A horizon, and especially the A_2 subhorizon, is a typical eluvial horizon, whereas the B horizon has all the earmarks of an illuvial one.

SOLONETZ VS. BLACK ALKALI

Glinka (1) and other Russian soil students state that "the American soil scientists call their Solonetz soils the Black Alkali". Apparently some other soil students (including the Americans) agree with this statement and are inclined rather to use the term Solonetz as an equivalent of "black alkali" and also to a rather liberal application of the theory of Solonchak-Solonetz-Solodi evolution for an explanation of the origin and nature of soils whose profiles may resemble the morphological characteristics of the true Solonetz. This is hardly advisable.

It is not yet definitely known whether or not Glinka's statement is entirely correct. It is possible that the Russian soil students would

recognize much of the black alkali soils as true Solonetz, and that the Americans would classify some of the Russian Solonetz soils as black alkali. The term "black alkali", however, is used largely in a chemical sense and no precise morphological definition of the profile has been attached to these soils except certain particular characteristics, whereas the Solonetz is defined primarily on the basis of its morphological profile.

Therefore, since the considerations which led to the definition of Solonetz and the black alkali soil are not identical, the terms cannot be used as mere synonyms. Indeed a large group of true Solonetz soils would never be considered as black alkali, as understood by American pedologists, and much of the black alkali has very little, if anything, in common with the true Solonetz. It is possible, however, that Gedroiz's definition of the Solonetz is clearer to the American conception of black alkali because both these are primarily chemical concepts.

THE SOLONETZ-LIKE SOILS IN SOUTHERN CALIFORNIA

MORPHOLOGY

The writer examined 25 profiles of different soils in southern California recognized as having a Solonetz morphology. These profiles do not represent all the soil series listed in Storie's work. They do represent, however, some of the conspicuous soil formations of this group, such as the Huerhuero and the Las Flores series. Again these profiles do not represent the Solonetz-like soils from every part of California where these soils are known to exist. All soils discussed in this paper are located in the Oceanside and Capistrano areas about halfway between Los Angeles and San Diego. It is assumed, however, that a habitat of pedogenesis in these particular areas is fairly typical for the great part of the area of these soils, with the possible exception of the region of Central Valley. Therefore, it is believed that the 25 profiles that were examined represent rather well the general condition under consideration, although it is not intimated that they illustrate precisely the entire problem and that no other conditions exist beside that represented by these 25 profiles.

In each case a fresh cut through the soil was made to a depth ranging from 5 to 8 feet. The soil designated as Huerhuero fine sandy loam has been examined in nine places; the soils of Las Flores series in eight places; and those included in the Olivenhain, Aliso, Monserate, and Merriam series in two places each.

All these soils are characterized by "two story" profiles. The upper, relatively friable, rather sandy, and light-colored layer has an average thickness of about 16 inches but varies from less than 1 inch to more than 4 feet. A considerable variation in thickness of this layer has been found in connection with the irregularities of the soil surface. The natural surface of the areas occupied by the Huerhuero, Las Flores, and probably the other soils is characterized by a conspicuous microrelief composed of small gently rounded mounds from 1 to 4 feet high and irregular intermound depressions. The sandy layer, as a rule, is very thin and even absent in many of the depres-

sions, whereas on the mounds it attains its maximum thickness. This layer rests upon the compact clay substratum, and apparently the surface of the latter has a more even character than the surface of the soil itself. A rather abrupt change from one layer to the other has been found in nearly all cases.

The sandy layer does not show any advanced development of the horizons. Regardless of its thickness it is very uniform in texture and consistence from the top to the bottom, save for a certain compaction near the surface. It has a light brownish-gray or dull grayish-brown color which is somewhat darker near the surface, due to a slight increase in content of organic matter. A distinct and sometimes strong bleaching just above the surface of the clay has been observed in most cases. This is especially pronounced when the total thickness of the sandy layer does not exceed 2 feet. In most cases, a slight mottling with iron stains occurs in connection with this discoloring of the lowest part of the layer. The laminated structure or any traces of its development were not found in any of the profiles examined, although a very slight and indistinct stratification of the material has been observed several times.

The lower layer, which is composed of the heavy clayey material, shows more definite differentiation of the horizons. A relative degree of this development depends upon the thickness of the overlying sandy layer. In the intermound depressions, especially where the clay is not covered by other soil material, it has a dark drab-gray or dark brown, in places even black, color which grades into light olive gray at a depth ranging from several inches to about 1 foot. During dry periods the soil is broken into large, irregular clods by the wide and rather deep cracks. On the mounds and elsewhere, where the thickness of the covering sandy layer exceeds 2 feet, the clay hardly shows any indication of a development of this horizon. It has a rather light drab olive-gray color which remains more or less uniform to a considerable depth if the clay is not underlain by a different geological stratum. It does not crack and does not show any development of structural aggregates.

The best development of the pillared horizon resembling that of the Solenetz soil was found between the two extremes mentioned above, namely, where the thickness of the sandy cover ranges from about one-half to no more than 2 feet. In such cases usually a distinct horizon from about 4 to 10 inches thick occurs. It is very dark gray or almost black in the Huerhuero and Las Flores soils; dark brown to chocolate brown in the Olivenhain and Aliso soils; or somewhat pinkish or reddish brown in the Monserate and Merriam soils. In all cases, it is characterized by a conspicuous coarsely pillared or "prismatic" structure produced by cracking of the clayey soil. The aggregates vary from about 1½ to more than 4 inches in diameter and usually their vertical axes are from two to three times longer than the horizontal axes. As a rule, the prismatic breakage is better developed at the top of the horizon where a very rough semblance of the irregular pentagonal or hexagonal prisms occasionally can be found. These seldom extend downward for more than 3 or 4 inches and grade into coarse sharp angular lumps without any particular

orientation. In most places the surfaces of the aggregates are darker colored than the insides and not infrequently appear to be slightly varnished. The material of the lumps in the B horizon of Las Flores and Huerhuero soils usually have a dark drab olive or yellowish-olive color and the material is thoroughly penetrated by thin fissures, pores, and veins, most of which have the same dark color and glossy appearance as the surface of the aggregates. The tops of the "prisms" are nowhere actually smoothly rounded, neither are they flat. In most cases they have a very light gray (ash-gray) color which characterizes also a thin layer of the friable material above the tops of the prisms. In several instances it has been found that this finely pulverized and strongly bleached material penetrates the pillar horizon through the cracks and pores to a depth of 1 or 2 inches below the upper boundary of the horizon.

The lower boundary of the horizon is very indistinct. The dark-colored coating and glaze may continue occasionally as far as the cracks go. The general dark color of the horizon, however, fades rather quickly, and grades into the typical olive gray or yellowish-gray or brown color of the deeper substratum. In many places, a considerable amount of salts, especially lime, has been found in the material under the dark-colored horizon. The occurrence of lime is not a constant characteristic. It has not been depicted by the treatment with hydrochloric acid to the depth of 70 to 80 inches in 11 of the 25 profiles examined by the author. More often it occurs in the Huerhuero soils, but only occasionally it is present in the substratum of the Las Flores and Olivenhain soils.

A cross section of the soil from the top of the sandy mound to the center of the depression where the clay is exposed on the surface shows that all indications of the horizon development gradually fade with the increase of the thickness of the sandy layer (Fig. 1).

Despite a general Solonetz-like appearance, none of the 25 soil specimens examined by the author has the precise morphology of genuine Solonetz. In addition to this, in no case could a definite conclusion be made that the different sections of their profiles represent the true genetic horizons. On the contrary, it appears almost certain that most of the individual characteristics of these sections are inherited from the stratified parental material, but are not developed through a pedogenic process. This can be proved by a comparison of the profiles having different thicknesses of the upper layers. If this layer were an eluvial horizon developed from a homogeneous parent material, then its greater depth would indicate an advanced and more profound leaching, which in turn should be accompanied by a correspondingly strong development of the B horizon. The facts show that not only is this not the case, but on the contrary, that a development of a horizon resembling the B horizon rapidly dwindles under the increasingly greater thickness of the upper layer. If the latter were an eluvial horizon, it would also be very difficult, if possible at all, to explain its conspicuously greater depths on the relatively elevated areas such as mounds, because it would stand out in sharp contrast to a normal relationship between the local topography and the energy of profile development. It is definitely established

that the normal thickness of the genetic soil horizon varies according to the microrelief and the mesorelief from its minimum on the elevated points to the maximum in the depressions.

The thickness of the clay layer is often not greater than 2 or 3 feet. Not infrequently this layer rests on different material, such as sandy or gravelly marine deposits. In some instances the boundary between these layers is very sharp, in the other cases the content of sand increases gradually. Occasionally the thin and sharply separated strata of clay and sandy material are interbedded, showing a definite stratification.

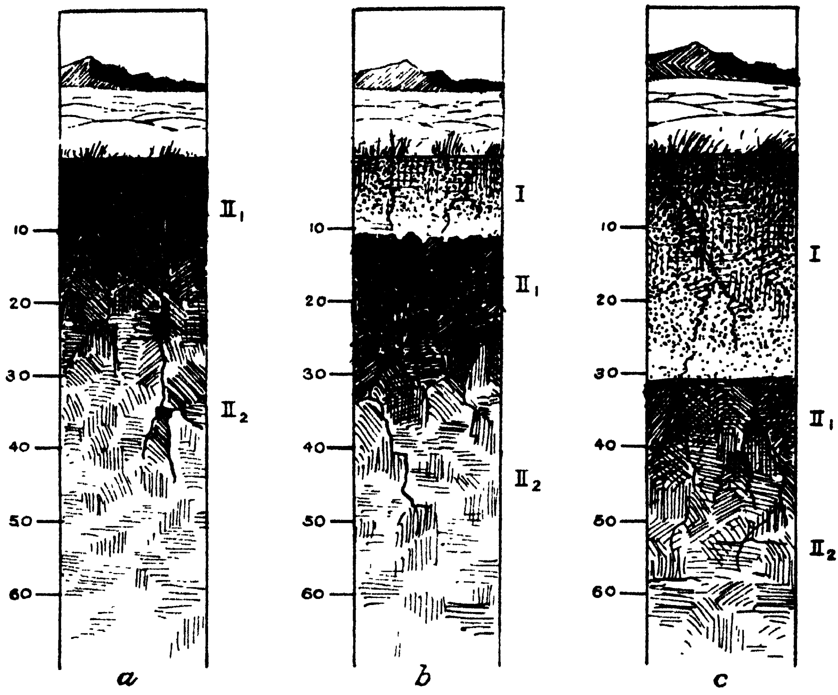

FIG. 1.—Cross section of Solonetz-like soil.

The origin of this material as well as the origin of its stratification is apparently different in various instances. In many cases it represents the stratified marine deposits; in other instances it is the fresh water or stream alluvium or the local deluvial drifts. The clay layer is formed of transported and redeposited material in many places but not wherever it is present. In many cases it may be formed *in situ* by weathering, whereas the upper and sandy layer is typically formed by the rather recent deposition of the drifts brought from the outside either by the water or wind, or by both these working alternatively.

It must be pointed out, however, that an arrangement of the soil profile of the genuine compact, clayey B horizon and of the less compact and looser A horizon is very common, if not typical, in the region.

In such cases the differences in texture of various horizons are actually developed in connection with the soil formation and usually are easily distinguishable from those representing an arrangement due to a stratification, although not infrequently a precise definition as to whether a profile represents a true pedogenetic development or a mechanical stratification is rather difficult.

All these facts lead to the conclusion that the loose sandy and compact clayey layers of many of the so-called Solonetz or Solonetz-like soils in southern California do not owe their physical distinctions to the processes of eluviation and illuviation, respectively, but inherit them directly from the mechanical layers of parent material. In other words, the so-called Solonetz morphology of many of these soils is not a morphology acquired through a pedogenic development but is due to a mechanical accumulation of the parent material.

It must be remembered, however, that a mere composition of the parent material of the two or more different strata does not make a development of the Solonetz impossible. The Solonetz type of soil formation, like the other genetic types, does not depend upon the kind of parent material. The Solonetz can be formed from a stratified parent material as well as from a homogeneous one.

Since neither mechanism nor chemistry of the Solonetz formation are definitely known as yet, it is difficult and not infrequently almost impossible to decide precisely as to whether or not the stratified parent material has been affected by this particular pedogenic process and, if so, then to what extent.

A difference in texture, consistency, and color of the two sections of the soil profile, and especially the so-called prismatic structure of the upper part of the second layer, were the main reasons for a supposition that these soils may be of the Solonetz type. Apparently these two sections were recognized as the true genetical horizons, although no evidence in support of this was present.

It has been pointed out in the beginning of this paper that a morphology alone is not sufficient basis for an identification of the soil type, unless it represents a true pedogenic development. A composition of the parent material from different layers leads not infrequently to soil mimicry, i.e., mechanical imitation of the genetic profile, regardless of the nature of the pedogenic process.

A mechanical arrangement of the pseudo-Solonetz profile may result from a composition of parent material similar to that described above. The upper part of the compact clayey layer in such combination very often develops a semblance of prismatic structure. An imitation of the details of the normally developed Solonetz profile is perfected further by an actual leaching and mechanical redistribution of certain materials because of the textural differences of the various layers. The permeability of the upper layer is greater than that of the underlying clay, owing to its coarser texture and porosity. This facilitates a mechanical infiltration of the finely textured material from the surface downward and its precipitation on the surface or in the cracks and pores of clay. Due to an infiltration of some colloids, especially of the organic colloids, the upper part of the clayey layer acquires a darker color and a more or less varnished appearance

in the cleavages. During wet seasons, when most of the cracks in the clay are closed, an excess of moisture saturates the lower part of the sandy layer, creating a temporary anaerobic condition there. This not uncommonly stimulates a local glei formation, a strong bleaching of the surface of the clay and of the material just above it, and an occasional mottling with iron stains.

All these changes lead to a very close imitation of the genuine Solonetz morphology. It is not intimated by any means that all the Solonetzlike soils in southern California are in reality the pseudo-Solonetz only, although the latter apparently are rather common among the soils having a Solonetz morphology. Not only do these soils lack a normal Solonetz origin, but their distribution and more likely a habitat are different from those of the true Solonetz. Kelley and Shaw (5) state that "these soils occur in extensive bodies and on surfaces of varying topography and relief. They occupy undulating terraces, nearly flat plains, or steeply sloping uplands of old secondary soils. The occurrence of the characteristic morphological features is not associated with microrelief, but is general over broad areas". This stands out in sharp contrast to the typical occurrence of the true Solonetz in complexes with other soils.

CHEMISTRY

Since chemistry of the Solonetz formation is not precisely known, a knowledge of the chemical profile of the so-called Solonetz soils of California would be of little help for a correlation of the latter with the other soils having a similar morphology. The chemical characteristics, however, are interesting in themselves because of their bearing on soil genesis.

A chemical study of these soils has been made by Kelley (4) who reports on seven profiles pointing out that entirely too few of the profiles have been investigated to warrant broad generalization. Kelley studied two profiles representing the Antioch series, two the Huerhuero series, and one each of the Aliso, Cachuna, and McClusky series. All these profiles represent the "two story" soils similar to those described above. Two samples of the lower (or clayey) layer, designated as B_1 and B_2, were taken for analysis from all but one profile, whereas only one sample representing the upper (or sandy) layer was analyzed in each profile with an exception of the profile of Solano Antioch. The sandy layer of the latter profile is represented by the three samples designated as A_1, A_2, and A_3 (Table 1).

Since it is not certain that the two layers of the profiles represent the true genetic horizons, it is impossible to consider the chemical differences of the samples from different layers as representing the result of pedogenic development. It is very possible that to a greater extent these differences are inherited from the pre-existing parent material; therefore, only a comparison of the samples representing each layer separately can be considered safely as representing the actual pedogenesis.

The upper layer of the Solano Antioch profile is represented more completely than those of the other soils. The content of water-soluble

TABLE 1.—*Analysis of the Antioch soil from Solano County, California, after Kelley.*

Layers and horizons	Depth, in.	Water-soluble salts, p.p.m.						
		HCO_3	Cl	SO_4	Ca	Mg	K	Na
1-A_1	1-9½	61	27	57	5	0	31	43
1-A_2	12-17	61	18	37	5	0	19	35
1-A_3	17-18	61	27	41	5	0	14	50
2-B_1	19-24	76	27	31	8	0	18	49
2-B_2	27-38	350	35	31	10	0	24	152

Layers and horizons	Total replaceable bases, M. E.	$CaCO_3$ M.E.	Fusion analysis %			
			SiO_2	Al_2O_3	Fe_2O_3	Ratio $\frac{SiO_2}{Al_2O_3}$
1-A_1	8.4	0	77.86	11.26	2.20	11.7
1-A_2	8.4	0	78.70	10.97	2.18	12.2
1-A_3	9.3	0	78.62	11.03	2.32	12 1
2-B_1	25.0	0	70.63	14.03	3.84	8 5
2-B_2	24.9	6.85	73.20	12.88	2.66	9.7

salts, fusion analysis, and especially the total exchange capacity of the soil which, as Kelley states, is a "rough measure of the clay and humus content" in all three samples of this layer show a remarkable uniformity of inorganic composition of the latter throughout its full extent (about 8 inches), or a lack of the development of any horizons within this layer. This is in full harmony with the conclusion based on study of morphology of these soils. The third sample of this layer (A_3) represents a soil from the depth of 17 to 18 inches from the surface, and the next sample (B_1), representing the top section of the lower layer, has been taken from the depth of 19 to 24 inches. A comparison of chemical data regarding these two samples shows a strikingly sharp change from one layer to the other. The latter is perfectly clear also on the photographs of this and a similar (Olivenhain loamy fine sand) soil illustrating the papers of Kelley and Shaw (5) and that of Storie (11).

A sharp, even abrupt change, from A_2 to B_1 horizons is indeed a typical feature of the true Solonetz. This conspicuous sharpness, however, never obscures an origin of such characteristics from the normal development of the adjoining horizons. A close examination of the photographs, on the other hand, leaves no doubt that a change of soil properties in these particular cases is not a result of development but is due to a deposition or stratification of the parent material.

A comparison of the data obtained by analysis of the B_1 and B_2 samples shows a considerable leaching of the top section of the lower or clayey layer that is designated as B_1 and ranges in thickness from 5 to about 8 inches. This is shown by a complete removal of the $CaCO_3$ from the B_1 horizon, and also by a great increase of water-soluble

salts in the B_2 horizon. We assume that prior to the development of the horizons the material of the entire layer was uniform as regards its inorganic composition, and especially the content of soluble salts.

The fusion analyses of Kelley show that SiO_2 increases with depth from B_1 to B_2, whereas the content of sesquioxides of aluminum and iron in the B_1 horizon is considerably greater than that in the B_2 horizon. The silica-alumina ratio of the Solano Antioch soil is 8.5 in the B_1 and 9.7 in the B_2 horizons. A relative decrease of silica in the B_1 may be caused by an increase of sesquioxides in this horizon, and these may be shifted into this horizon from the sandier upper layer by leaching.

The leached part of the clayey layer acquires a dark color, probably due, at least in part, to a removal of lime, and a roughly prismatic breakage in a dry condition. The analysis shows that leaching removed from the B_1 horizon not only the readily soluble salts but also the alkali earth carbonates. The latter disappear from the B_1 completely, whereas a small amount of the former may be present in either the leached section of the clayey layer and in the upper or sandy layer. This apparently is a result of a secondary, maybe seasonal, capillary rise of the water-soluble salts toward the soil surface, although, generally speaking, the content of these salts here is not much greater than normal in many other soils.

Since the leaching of the top section of the clayey layer is performed by percolating water and since no evidence is present that it might have been produced before this layer has been covered by the sandy material of the upper layer, it can be assumed that the upper layer is also subject to leaching and that at least some of its characteristics *are* due to the leaching and eluviation. This is in harmony with the conclusion regarding the possibility of some perfection of the mechanically arranged Solonetzlike profile.

In the soils analyzed by Kelley the thickness of a sandy layer ranges from 12 to about 19 inches; therefore, it is impossible to draw any conclusion as to the extent of the protective influence of the greater thickness of the sandy layer upon the leaching of the top section of the clay and upon the development here of some Solonetz-like characteristics. This protection, however, is apparent as shown by studies of the morphology of these soils.

Consequently, chemical analysis shows that the "two story" parent materials of the so-called Solonetz soils of California are affected by leaching, due to which the upper layer may acquire some characteristics of the eluvial horizon and the upper part of the lower layer some properties of the illuvial horizon. Since no similar analyses of the other soils of the region, developed from different parent materials were made, it is impossible to say whether such a development is due entirely to the particular physical composition of parent material, or that it is a regional characteristic common to these and to the other soils.

In neither case can it be regarded as a specific indicator of the Solonetz formation.

SUMMARY

Some soils in southern California are characterized by the profiles which are similar morphologically to those of the Solonetz. It has not been certain, however, whether or not these soils are the true Solonetz. A precise definition of the real nature of the soil requires an examination of its morphology, chemistry, and genesis and their comparison with those of the established soil types.

This study shows that a Solontzlike morphology of some of the so-called Solonetz soils of southern California has not been developed through the normal soil-forming process but is due to the specific character of their parent material; therefore a morphological similarity of these soils with the true Solonetz cannot be considered as a proof of their Solonetz nature.

A general character of distribution of these soils and a character of other soils with which the former are associated and of an environment of their formation are not similar to those of the true Solonetz soils.

Therefore, it appears more likely that the so-called Solonetz soils of southern California are not the true Solonetz but should be regarded as pseudo-Solonetz or Solonetzlike soils because of morphological similarity of their profiles with those of the true Solonetz soil. This similarity is nothing more than a mechanical mimicry.

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NOTE

AN AUTOMATIC WATERING SYSTEM FOR POT CULTURES[1]

AN automatic watering system that maintains a definite degree of saturation, unaffected by transpiration rates, is highly desirable in pot culture experiments which are used extensively for the investigation of the factors concerned in plant growth.

Sand or soil in a vertical tube having one end in contact with water becomes wet for a considerable distance above the level of the water. The moisture content at any point in the tube is a function of the distance above the water level and the particle size of the sand or soil. The water content of the sand or soil at any specific point along the length of the tube is affected by any change in the water level. The water system described in this paper operates on these principles.

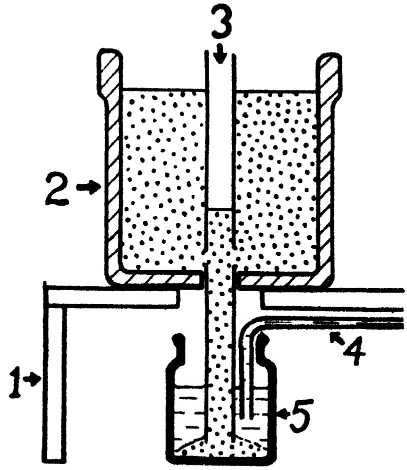

FIG. 1.—Vertical tube method for the automatic control of the moisture content in sand cultures.

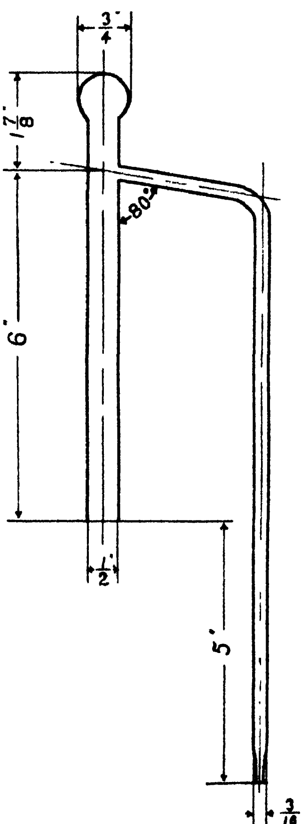

FIG. 2.—A modified U-tube.

The system consists essentially of an open tube, filled with sand, having one end extending into a water supply and the other in contact with the culture. For convenience in filling the tube, and elimination of air pockets, the tube is extended above the surface of the culture, and contact with the culture made through holes in the wall of the tube at a point near the bottom of the pot. Fig. 1 shows the assembly of the parts.

[1]The investigation reported on here is in connection with a project of the Kentucky Agricultural Experiment Station and is published with the permission of the Director.

The bench (1) supports the pot (2) above the water supply in the bottle (5). The perforated tube (3) extends through a hole in the pot and bench into the water in the bottle. Water is supplied as required through the siphon (4) from a constant-level bottle. The source of water can be either glass reservoirs or city mains, the regulation of flow being obtained by air displacement of water or by float-operated valves, respectively.

A modified method of supplying water to the culture from a constant-level source has been developed for experimental cultures requiring a high degree of exactness in their chemical treatment. This method does not require a hole in the bottom of the pot, and is therefore suited for use with porcelain and other expensive pots. Contact between the culture and the water supply is made by a U-tube modified as shown in Fig. 2.

The diameter of ½ inch of the larger tube assures positive contact with the sand in the pot. The smaller tube for the side arm allows several tubes to be inserted into the neck of a single water bottle. The bulb acts as an air trap for any gases that may collect in the tube. The dimensions given are suitable for ½-gallon sand cultures. The assembly of the system is shown diagramatically in Fig. 3.

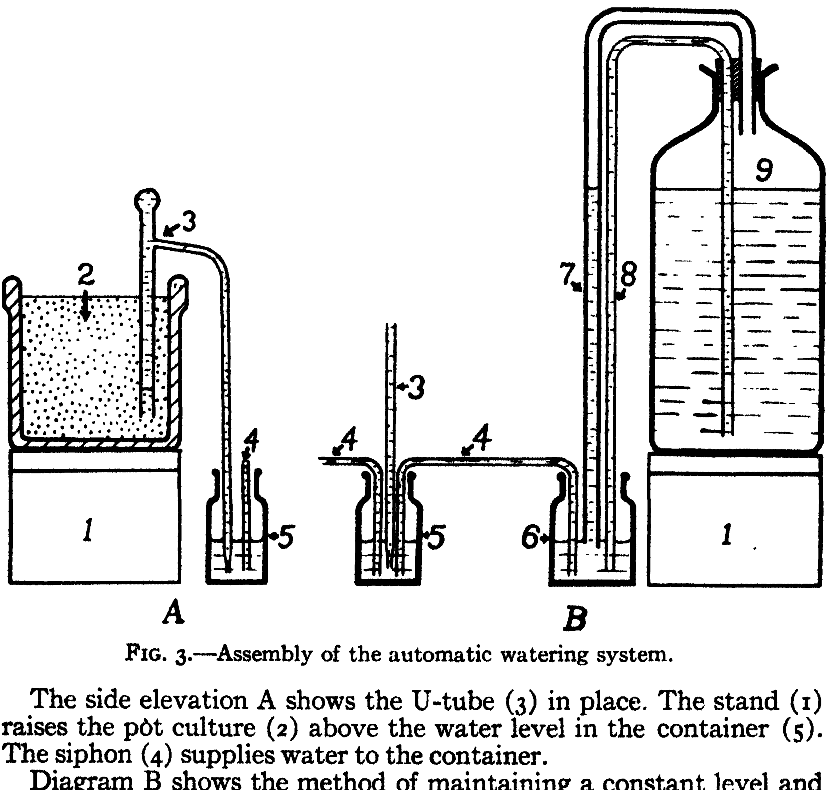

FIG. 3.—Assembly of the automatic watering system.

The side elevation A shows the U-tube (3) in place. The stand (1) raises the pòt culture (2) above the water level in the container (5). The siphon (4) supplies water to the container.

Diagram B shows the method of maintaining a constant level and the connection of the water bottles by means of siphons. The numbers 1, 3, 4, and 5 represent the corresponding parts shown in A. The con-

stant-level bottle (6) controls the admission of air through the tube (7). The siphon (8) allows the water to flow from the reservoir (9) as it is required.

The principles of operation are the same as in the previous method. The surface attraction of the culture for water is constant. Removal of water from the culture by evaporation or the transpiration of plants results in absorption of water by the culture from the tube, reducing the pressure at the point of contact, and atmospheric pressure forces water from the supply bottle into the tube as rapidly as it is removed by the culture.

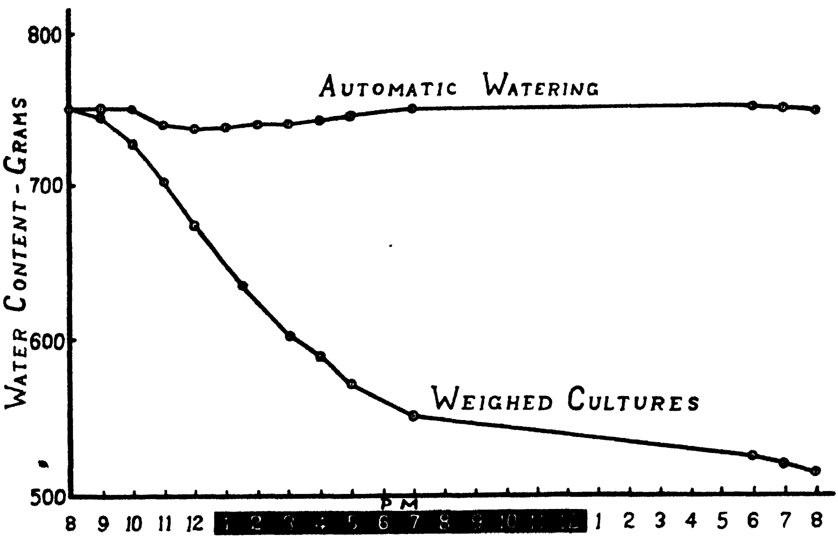

Fig. 4.—Comparison of the water content of automatically watered cultures with water losses in weighed cultures.

The long arm of the U-tube functions as a siphon, presenting a force that acts in opposition to the surface tension of the culture. An increase in the effective length of the siphon reduces the influence of surface tension and results in equilibrium of the forces at a lowered degree of saturation. Since any change in the water level in the bottles changes the effective length of the siphon, the degree of saturation is most conveniently regulated by adjustment of the water-level.

The water level in the supply bottle (5) is kept constant by a flow of water through the siphon (4) from the regulating bottle (6). The removal of water from the bottle (6) allows air to bubble through the tube (7) into the reservoir (9), displacing sufficient water through the siphon (8), to maintain a constant water level in the system. The water level is regulated by raising or lowering the air tube (7).

Rapid increases in temperature affect the operation of the system, since a temporary flow of water results from thermal expansion in the reservoir. A bottle of relatively large diameter connected to the constant-level bottle, or a sufficient number of cultures supplied by the same reservoir, will absorb the spontaneous flow due to thermal ex-

pansion with no effective change in the water level, since the factors that affect rapid rises in temperature are usually conducive to an increased rate of transpiration.

The efficiency of the automatic system in supplying water to plants in pot cultures has been determined by observing the loss in weight of the cultures during periods of rapid transpiration. Cultures having a total moisture content of 750 grams of water averaged 25 grams below weight during the middle part of the day. The plants in the cultures transpired an average of 1,500 grams of water during a period of 24 hours. This loss in weight was proportionately less during periods of more restricted transpiration, and is considered a loss of weight from the plant itself rather than from the culture. The comparative water contents of cultures watered automatically and by weighing are shown in Fig. 4.

Six cultures of tobacco, comparable in all respects, were used in each group. All cultures at the start contained 750 grams of water. The water content of the cultures watered automatically remained fairly constant, while the weighed culture lost water rapidly from the start and at the end of 24 hours required an average of 234 grams of water to bring the moisture content back to the proper degree of saturation.—R. K. CALFEE and J. S. MCHARGUE, *Department of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky.*

AGRONOMIC AFFAIRS

DR. F. B. SMITH NAMED SECRETARY-TREASURER

PRESIDENT F. D. Richey has named Dr. F. B. Smith to act as Secretary-Treasurer of the American Society of Agronomy for the unexpired term of the late Dr. P. E. Brown. Doctor Smith, formerly of Iowa State College and now with the Florida Agricultural Experiment Station, at Gainesville, Fla., served one term as Secretary-Treasurer during the year Dr. Brown was President of the Society, hence is familiar with the duties of the office. The records and books of the Society have been removed to Gainesville and all communications to the Secretary-Treasurer should be addressed to Doctor Smith at Gainesville.

At the same time President Richey has designated Dr. J. B. Peterson of Iowa State College, Ames, Iowa, to act as Assistant Secretary to have charge of the mailing out of back numbers of the JOURNAL, a large stock of which is in storage in Ames.

RECOMMENDATIONS FOR TOBACCO FERTILIZERS FOR 1938

RECOMMENDATIONS with reference to the fertilization of flue-cured, sun-cured, and shipping tobacco grown on average soils in Virginia, North and South Carolina, and Georgia in 1938 as prepared by the Tobacco Research Committee comprised of representatives from the agricultural experiment stations of the states mentioned and from the U. S. Dept. of Agriculture, are now available in mimeographed form. Copies may be obtained by addressing requests to Dr. C. B. Williams, Chairman, Tobacco Research Committee, North Carolina Agricultural Experiment Station, Raleigh, N. C.

Attached to the fertilizer recommendations are suggestions for the control of tobacco diseases in 1938 and recommended control measures for insect pests of growing tobacco.

TENTATIVE PROGRAM FOR THE MEETING OF THE CROPS SECTION AT CHICAGO, DECEMBER 1-3

MEMBERS of the Society who plan to present papers on some phase of crops, are urged to communicate their intentions to O. S. Aamodt, chairman of the Crops Section, University of Wisconsin, Madison, Wisc., by October 15. The title of the paper, a brief summary, and the length of time required for presentation must be at hand by that date for use by the Editor in supplying information to news agencies and special science writers. Papers will be accepted as late as November 1; however, only those received prior to October 15 will be available for news releases.

The following program is tentative subject to final plans for the meeting of the Society as a whole.

WEDNESDAY MORNING, DEC. 1

Section 1. The physiology of crop plants. Ide P. Trotter, Chairman.
Section 2. Vegetative aspects of soil erosion. G. W. Musgrave, Chairman.
Section 3. Miscellaneous papers. L. E. Kirk, Chairman.

WEDNESDAY AFTERNOON, DEC. 1

Section 1. Round table discussion: Weather-crop relations. John H. Parker, Chairman.
Section 2. Round table discussion: Recent developments in nitrogen fixation by leguminous plants. (Joint program with Soils Section III, Soil Microbiology.) E. B. Fred, Chairman.

THURSDAY MORNING, DEC. 2

General Program of Society

THURSDAY AFTERNOON, DEC. 2

Section 1. The morphology of the cotton plant and cotton fiber. Ide P. Trotter, Chairman.
Section 2. Round table discussion: Induced polypoidy in relation to plant breeding. R. A. Brink, Chairman.
Section 3. Round table discussion: Barley improvement. T. E. Stoa, Chairman; Gus Wiebe, Secretary.
Business meeting of Crops Section.

FRIDAY MORNING, DEC. 3

Section 1. Miscellaneous papers not scheduled in special program. O. S. Aamodt, Chairman.
Section 2. Round table discussion: Policies regarding the release, distribution and certification of inbred lines of corn and corn hybrids. Merle T. Jenkins, Chairman.

FRIDAY AFTERNOON, DEC. 3

Section 1. Round table discussion: Statistics. George W. Snedecor, Chairman.
Section 2. Round table discussion: Observations at the Fourth International Grassland Congress. P. V. Cardon, Chairman.

Arrangements for meetings and programs are also being made by the following groups: International Crop Improvement Association, A. L. Clapp, Secretary; Agricultural Extension Workers, O. S. Fisher, Chairman; Seed Council of North America, A. L. Stone, Secretary.

Miscellaneous papers will be classified according to subject matter. Thus, all papers on pastures, grains, etc., will be placed together. Additional sections may be provided if necessary. Special committees can arrange to meet at noon luncheons, between 4:30 to 6:00 p.m., and on the evening of Wednesday, December 1.

NEWS ITEMS

DR. F. B. SMITH, Research Associate Professor of Soils, Iowa State College, has resigned to accept the position of Professor of Soils, University of Florida, effective September 1.

DR. O. C. BRYAN has resigned his position with the Florida Experiment Station to become Research Director for Dolomite Products, Inc., of Ocala, Fla.

DR. L. D. BAVER has resigned his position as Assistant Professor of Soils at the University of Missouri to accept the post of Professor of Agronomy at Ohio State University.

D. W. THORNE, formerly Assistant Professor of Soils at Iowa State College, has accepted the position of Associate Professor of Soils at the Agricultural and Mechanical College of Texas, College Station, Texas

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CONTROL OF WEEDS IN LAWNS WITH CALCIUM CYANAMIDE[1]

D. G. STURKIE[2]

IN the southeastern states the summer lawn grasses are usually dormant in the winter and the lawns are frequently infested with plants that grow during the winter and produce seed in the spring. Such weed plants are unsightly, shade the grass, reduce its vigor, and when they die leave areas bare of vegetation. A treatment that would control weeds and at the same time stimulate the lawn grasses would be desirable

Calcium cyanamide is a common source of commercial nitrogen which has herbicidal properties. Experiments with the use of cyanamide as an herbicide on lawns were begun at the Alabama Agricultural Experiment Station in 1932. These experiments were devised to determine the effect the treatment would have on weeds and on the lawn grass, and to determine the rate and time at which the cyanamide should be applied. Preliminary results were reported in 1933.[3] Further studies are reported in this paper.

Established lawns of Bermuda grass (*Cynodon dactylon* (L.) Pers.) were used in the experiments. The cyanamide was broadcast by hand, usually in the middle of the day when there was no dew on the plants. It was found that the cyanamide was more effective if applied when the plants were wet, but the applications were made when the plants were dry in order to make the test under the most unfavorable conditions. The percentage of weeds killed was determined about two weeks after the applications had been made. When the Bermuda grass had begun active growth, notes were taken on its condition.

DATE OF APPLICATION

On the dates shown in Table 1, plats were treated with granular cyanamide at a rate of 1,500 or 2,000 pounds per acre. It was found that the weeds could be killed usually without injury to the Bermuda

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication June 16, 1937.
[2]Associate Agronomist.
[3]Jour. Amer. Soc. Agron., 25:82–84. 1933.

grass if the treatments were given any time from December 1 to March 1. In the winter of 1932, treatments in December and January resulted in damage to the grass the next spring. This is the only evidence of such injury. During this winter, the weather was very mild in the month of February and the Bermuda grass on the plats treated in December and January began growing rapidly. A freeze occurred on March 6 and killed the tops of the grass. It is probable that the active growth of the plants had exhausted the reserve food and when the tops of the plants were killed, they were weakened and were slow to recover and resume active growth. The grass on all of the damaged plats recovered and produced an excellent lawn by June 15.

TABLE 1.—*The percentage of weeds killed and the condition of Bermuda grass when treated with granular cyanamide at different dates.**

Plat No.	Date of application	Weeds killed %	Condition of Bermuda grass on May 4
		Winter of 1932	
1	Dec. 1, 1932	100	Badly injured
2	Jan. 6, 1933	100	Badly injured
3	Feb. 2, 1933	100	Excellent
4	March 3, 1933	100	Excellent
5	Apr. 1, 1933	100	Injured
6	Untreated	0	Stunted and yellow
		Winter of 1933	
1	Dec. 20, 1933	99.9	Excellent
2	Jan. 17, 1934	99.9	Excellent
3	Feb. 15, 1934	99.8	Excellent
4	Mar. 16, 1934	99.7	Excellent
5	Untreated	0	Stunted and yellow
		Winter of 1934	
1	Jan. 18, 1935	100	Excellent
2	Feb. 18, 1935	100	Excellent
3	Mar. 13, 1935	100	Injured
4	Untreated	0	Stunted and yellow
		Winter of 1935	
1	Jan. 20, 1936	99.5	Excellent
2	Feb. 25, 1936	99.5	Excellent
3	Mar. 15, 1936	99.6	Badly injured
4	Untreated	0	Stunted and yellow

*The rate of application was 1,500 pounds per acre in 1932 and 2,000 pounds per acre in the other years.

When treatment was delayed until after March 1, there was injury to the grass in some cases; however, the injury was only temporary as the plants soon recovered and made an excellent lawn by summer. Treatment at any time was very effective for the control of the weeds.

RATE AND METHOD OF APPLICATION

In the studies on rate of application of calcium cyanamide, the treatments used and the results obtained are shown in Table 2. An application of at least 1,000 pounds per acre was usually necessary to

kill all of the weeds. When an application of 2,000 pounds per acre was made after March 1, there was often injury to the Bermuda grass. However, in all cases, the grass recovered and produced an excellent lawn by the beginning of the summer. The delay in recovery was longer with larger applications; therefore, when an application of 2,000 pounds per acre or more is used, it should be applied before March 1.

TABLE 2.—*The percentage of weeds killed and the condition of Bermuda grass when treated with granular cyanamide at different rates.*

Plat No.	Pounds of cyanamide per acre	Weeds killed %	Condition of Bermuda grass on May 4
		Treated Feb. 2, 1933	
1	600	93	Excellent
2	1,200	100	Excellent
3	1,500	100	Excellent
4	2,000	100	Excellent
5	3,000	100	Excellent
6	Untreated	0	Stunted and yellow
		Treated Mar. 15, 1934	
1	500	90	Excellent
2	1,000	100	Excellent
3	1,500	100	Slight injury
4	2,000	100	Injured
5	Untreated	0	Stunted and yellow
		Treated Mar 13, 1935	
1	1,000	100	Excellent
2	2,000	100	Injured
3	Untreated	0	Stunted and yellow
		Treated Feb. 25, 1936	
1	1,000	94	Excellent
2	2,000	100	Slight injury
3	Untreated	0	Stunted and yellow

In the method of application studies, the calcium cyanamide was applied at the rate of 2,000 pounds per acre. On one plat it was all applied in one application but on another plat half of it was applied and two weeks later the remaining half was applied. The results are reported in Table 3. It was found that two applications gave a better control of the weeds than one application largely because weeds that were missed with the first application could be treated with the second. There was no difference in the effect on the Bermuda grass from one or two applications. It was usually desirable to make two applications for better weed control, but one application was satisfactory if care were taken to scatter the material uniformly over the area.

COMPARISON OF POWDERED AND GRANULAR CYANAMIDE

The cyanamide was applied at the rate of 2,000 pounds per acre on the dates shown in Table 4. At this rate the powdered and granular forms were equally effective in killing the weeds. In addition to the re-

TABLE 3.—*The effect of dividing the application of 2,000 pounds of granular cyanamide per acre on the percentage of weeds killed and on the condition of the Bermuda grass.*

Plat No.	No. of applications	Date of application		Weeds killed %	Condition of Bermuda grass on May 4
		First	Second		
		Winter of 1932*			
1	2	Feb. 20	Mar. 1	100	Excellent
2	1	Feb. 20	———	75	Excellent
3	2	Mar. 15	Mar. 29	100	Excellent
4	1	Mar. 15	———	25	Excellent
5	0	Untreated	———	0	Stunted and yellow
		Winter of 1933			
1	2	Feb. 18	Mar. 13	97	Excellent
2	1	Feb. 18	———	90	Excellent
3	0	Untreated	———	0	Stunted and yellow
		Winter of 1935			
1	2	Feb. 25	Mar. 15	99	Injured
2	1	Feb. 25	———	98	Injured
3	0	Untreated	———	0	Stunted and yellow

*Italian rye grass was used as the weed in the winter of 1932.

sults reported, a study for one year was made with rates varying from 100 to 2,000 pounds per acre. When the rate of application was below 1,000 pounds per acre, the powdered material was somewhat more effective than the granular, but at these rates neither form gave 100% control. The granular form is much easier applied.

TABLE 4.—*The percentage of weeds killed and the condition of Bermuda grass when treated with either powdered or granular cyanamide at a rate of 2,000 pounds per acre*

Plat No.	Form of cyanamide	Weeds killed %	Condition of Bermuda grass on May 4
		Treated Feb. 2, 1933	
1	Powdered	98	Excellent
2	Granular	98	Excellent
3	Untreated	0	Stunted and yellow
		Treated Jan. 17, 1934	
1	Powdered	99.7	Excellent
2	Granular	99.7	Excellent
3	Untreated	0	Stunted and yellow

EFFECTIVENESS OF CYANAMIDE IN KILLING VARIOUS PLANTS

Usually only a relatively few species of weeds occur in any one lawn; therefore, to test the effect of cyanamide on various plants, treatment was made on weeds wherever they could be found. In most cases the cyanamide was applied at the rate of 2,000 pounds per acre. In the case of wild garlic, treatment as high as 5,000 pounds per acre was given.

The following plants were killed by an application of calcium cyanamide at a rate of 2,000 pounds per acre:

Bitter-weed (*Helenium tenuifolium* Nutt.)
Chickweed (common) (*Stellaria media* (L) Cyrill.)
Chickweed (mouse-ear) (*Cerastium viscosum* L.)
Cranesbill (*Geranium carolinianum* L.)
Lesser wart cress (*Coronopus didymus* (L) Sm.)
Cudweed (*Gnaphalium purpureum* L.)
Bur clover (*Medicago arabica* Huds.)
Carolina clover (*Trifolium* sp.)
Hopclover (*Trifolium procumbens* L.)
White clover (*Trifolium repens* L.)
Black Medic (*Medicago lupulina* L.)
Dandelion (*Taraxacum officinale* Weber.)
Dwarf dandelion (*Krigia virginica* (L.) Willd.)
Hen-bit (*Lamium amplexicaule* L.)
Lespedeza (*Lespedeza striata* (Thunb.) H. and A.)
Mayweed (*Anthemis cotula* L.)
Peppergrass (*Lepidium virginicum* L.)
White plantain (*Plantago virginica* L.)
Ragweed (*Ambrosia artemisiifolia* L.)
Sheep sorrell (*Rumex acetosella* L.)
Wood sorrell (*Oxalis stricta* L.)
Italian rye grass (*Lolium multiflorum* Lam.)
Toad flax (*Linaria canadensis* (L.) Dumont)

The following plants were not killed by an application of calcium cyanamide at a rate of 2,000 pounds per acre:

Broom sedge (*Andropogon virginicus* L.)
Dock (*Rumex* sp.)
Carpet grass (*Axonopus compressus* Siv.)
Centipede grass (*Eremochloa ophiuroides* (Munro) Hack.)
Dallis grass (*Paspalum dilatatum* Poir.)
Purple bent grass (*Argostic hyemalis* (Walt) B. S. P.)
Flea-bane (*Erigeron* sp.)
Honeysuckle (*Lonicera japonica* Thunb.)
Evening primrose (*Oenothera laciniata* Hill)
Poke weed (*Phytolacca decondra* L.)
English plantain (*Plantago lanceolata* L.)
Wild garlic (*Allium vineale* L.)

It may be noted that the larger growing perennials were not killed and the plants that were most effectively controlled were annuals. In no case were the grasses killed that are commonly used for lawns in the lower South.

Experiments with eradication of Italian rye grass were made to determine whether the grass could be killed by treatment with cyanamide. Bermuda grass areas on which Italian rye grass had been seeded in the fall were treated with cyanamide at rates varying from 250 to 2,000 pounds per acre. Tests were also made to determine the best time of application.

The results showed that at least 1,000 pounds of cyanamide per acre should be applied. Making the treatment in two applications

was more effective than a single application. It was necessary to apply the calcium cyanamide by March 1 to kill the Italian rye grass. Thus, the value of the rye grass will be largely lost if it is killed at such an early date.

CONCLUSIONS

Calcium cyanamide was applied to Bermuda grass lawns in the winter to kill the annual weeds and to supply nitrogen for the lawn grass. The perennial plants were usually not killed by the treatment. The treatment was very beneficial to the lawn because of the removal of the weeds and the fertilization from the nitrogen in the cyanamide. The Bermuda grass was sometimes injured, but the injury was only temporary and the treatment finally was decidedly beneficial. The stimulation from the nitrogen continued throughout the summer and no additional nitrogen fertilization was necessary.

Either the granular or powdered cyanamide may be used. The granular material is easier applied and is therefore preferable. The rate of application should be from 1,000 to 2,000 pounds per acre. The cyanamide should be applied from December 1 to March 1. The preferable time is in January or early February.

Applying all of the cyanamide in one application is as effective as applying it in two applications if care be taken to distribute it uniformly. Since the application is usually not made uniformly, it is preferable to make two applications. If the treatment is made in two applications, it is desirable to make the first in December or January and the second in January or February.

The cyanamide may be applied when the weeds are either wet or dry. In the studies reported, it was made when the weeds were dry.

It is usually not desirable to kill Italian rye grass on lawns with cyanamide.

CAUTION

Treatment with cyanamide should be confined to Bermuda grass lawns. It should not be applied to bluegrass or other lawns. When applied to the soil, cyanamide will not injure shrubbery, but it should not touch the foliage. It should not be used around pines or other plants that require an acid soil.

THE NUTRITIVE RELATION OF COPPER ON DIFFERENT SOIL TYPES IN FLORIDA[1]

MAOMA F. HILL AND O. C. BRYAN[2]

IN recent years a number of papers dealing with the influence of copper salts on life processes have been published. Space will not permit a resumé of the literature here, but in general the results indicate that copper contributes to the life processes in a number of ways, namely, (a) oxidizing catalyst, (b) nutritive, (c) neutralizer of toxins, (d) fungicidal, and others. The exact function of copper on the life process is still obscure, yet the economical value of this element in agriculture, either as a fungicide or direct treatment of the soil, is well recognized in certain areas. Its use as a soil amendment has been increasing in importance within recent years.

The fact that copper is stored in the liver and other vital organs of newly born animals and in seeds of plants suggests its universal need in the metabolic processes of life; but because of the lack of refined chemical methods, it is difficult to demonstrate the exact function of copper in the life process. This is also true of other less abundant elements in plants, as well as some of the more abundant ones, such as potash which is indispensable, yet not known to exist as an integral part of proteins, carbohydrates, and fats.

Certain publications (1, 3, 4, 15, 17, and 19)[3] indicate that copper is indispensable in the forage plants on certain soil types; moreover, that the copper content of some soils may be too low for normal plant growth. Other publications (3, 8, 13, 14) indicate that copper is necessary for animal metabolism. Assuming that copper is nutritive, then it would be logical to expect a greater deficiency of this element in poor soils than in productive soils.

The nature of Florida soils, being comparatively low in metals (6), offers an opportunity to study the possible nutritive relations of copper on plant growth. The object of this paper is to determine the behavior of plants with varying amounts of copper on a variety of soil types.

METHODS OF STUDY

Representative samples of soil were collected from areas of virgin soils known to be inherently poor and on which "salt sick" of cattle was known to occur. "Salt sick" (3) is a disease of cattle resulting from a deficiency of iron and copper in the forage food. For comparison, samples were also collected from productive soils. In all cases composite samples of the surface 6 to 7 inches of soil were collected. The soils were then brought to the greenhouse and mixed individually and equal amounts (1 kilogram) of each soil placed in glazed earthenware jars. Each culture was then given 1 gram of the following nutrient mixture to supply the

[1]Contribution from the Department of Agronomy, University of Florida, Gainesville, Fla. Received for publication July 1, 1937.

[2]Graduate Student and Professor of Soils, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 813.

nutrients other than copper and nitrogen, the salts being thoroughly ground and mixed before using:

$Ca_3(PO_4)_2$	40	grams
$MgCa(CO_3)_2$	20	grams
NaCl	10	grams
KCl	10	grams
$MnSO_4$	8	grams
K_2SO_4	10	grams
$CaSO_4$	30	grams
$FePO_4$	40	grams
H_3BO_3	1/10	gram
$ZnSO_4.5H_2O$	5	grams

After the soils had been brought to two-thirds saturation with top water, they were planted to mustard seed. Mustard was chosen because of its rapid growth and the smallness of seed which carries only a small amount of reserve nutrients. When the seed had been planted, copper sulphate was added in amounts varying from 0.05 to 10 p. p. m., according to Table 1. Sodium nitrate was also added to each culture at the rate of 200 pounds per acre.

When the seed had germinated, they were thinned to 24 plants per culture and water added as needed. A second application of nitrogen was made 2 weeks after planting and the cultures allowed to grow for a period of 40 days at which time they were photographed, harvested, dried, and weighed. The oven-dry weights are given in Table 1. The comparative growth is in Fig. 1.

A second series of soils was potted in a manner similar to the first series and copper sulfate added at rates varying from 0.007 to 500 p. p. m. in order to determine the possible growth curve of mustard with copper. The plants were given essentially the same treatments, except copper, as previously described. When these plants were 50 days old, they were dried and weighed with the results shown in Fig. 2.

In order to study further the behavior of mustard plants to treatments of copper on different soil types, a third series of cultures were prepared using soils of a wide variation in fertility, namely, St. Lucie sand, Orangeburg fine sandy loam, and Peat. The St. Lucie sand is almost inert quartz, while the Orangeburg fine sandy loam and Peat have a fair natural fertility.

The plants were treated on these soils as in the previous cultures and allowed to grow for about 40 days. They were then dried, weighed, and the copper content determined according to the method of Elvehjem and Lindlow (7). The growth of plants in relation to the absorption of copper is given in Figs. 3, 4, and 5.

RESULTS

Examination of the data in Table 1 and Fig. 2 shows that copper produced measurable increases in the growth of mustard on all soils used, but the greatest response occurred on the soils of the lowest fertility. Quantities of copper as low as 0.007 p. p. m. produced no measurable increase in growth, while quantities from 0.1 to 5 p. p. m. produced measurable increases. Applications of 50 to 100 p. p. m. were toxic. The toxicity was greatest on those soils with the least buffer capacity; moreover, the toxic properties decreased with an increase in time after application. It is interesting to note that stimulation was produced even on the productive soils known to be free from "salt

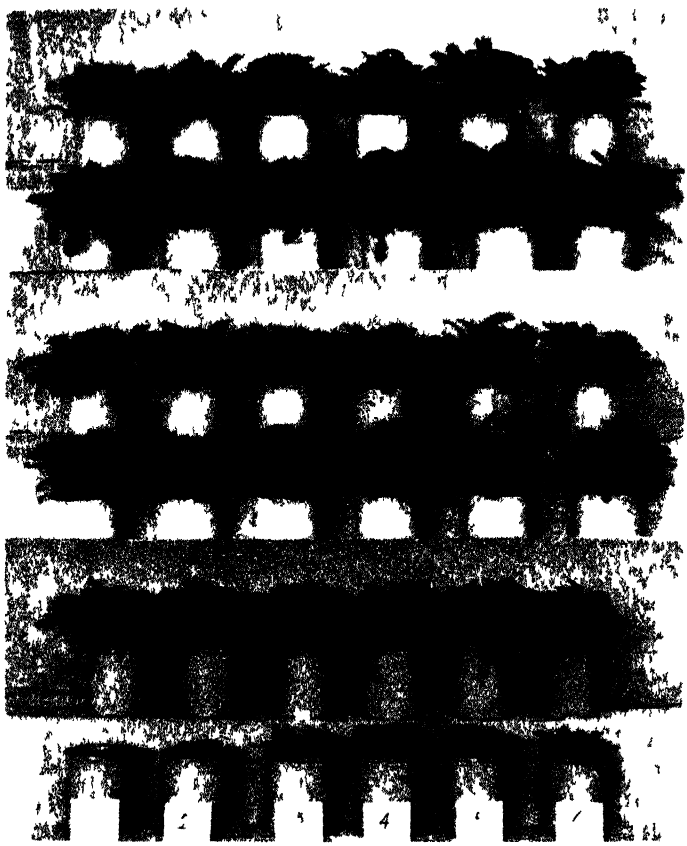

FIG. 1.—The growth of mustard on different soil types as affected by copper sulfate. Left to right all cultures No. 1 no copper, Nos. 2, 3, 4, 5 and 6, 0.05, 0.1, 1, 5 and 10 p.p.m. of copper respectively, all other factors constant.

sick" of animals. This would indicate that the soils now known to be healthy range lands were somewhat deficient in copper.

TABLE 1.—*The effect of varying amounts of copper sulfate on the growth of mustard*

Treatment of $CuSO_4$, p.p.m.	Growth (oven-dry weight) of plants on different soils, grams*					
	Gainesville fine sand	Norfolk fine sand	Norfolk sand	Leon sand	Blanton fine sand	Orangeburg fine sand
0.00	4.40	3.25	3.25	0.90	3.39	3.09
0.05	3.99	3.58	2.85	1.71	3.46	3.17
0.10	4.17	3.62	3.37	2.60	3.43	3.94
1.00	4.88	3.87	3.49	3.45	3.77	3.35
5.00	4.56	4.32	3.62	4.10	3.19	3.37
10.00	4.10	3.92	3.32	2.54	2.99	2.93

*The figures represent averages of duplicates.

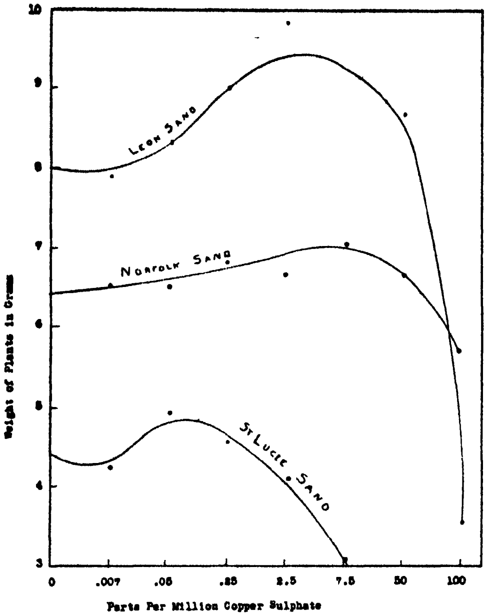

FIG. 2.—The influence of varying amounts of copper sulfate on the growth of mustard.

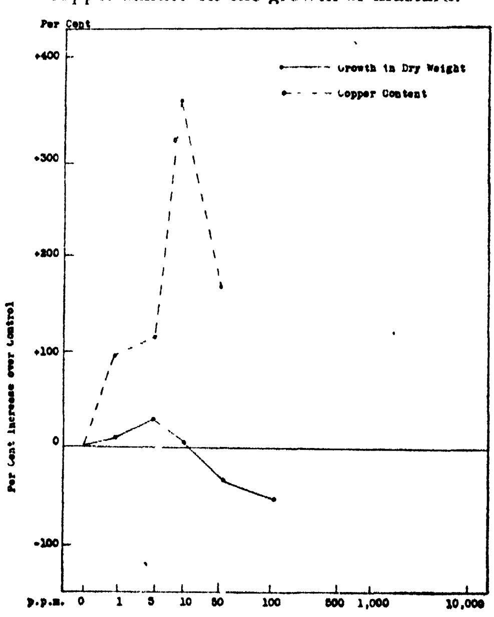

FIG. 3.—Increase of growth and copper content of mustard on St. Lucie sand with varying amounts of copper sulfate.

The results shown in Fig. 2 indicate that the growth behavior of mustard with copper treatments was similar to that of other nutrients, with the exception of an apparent depression in growth with only small amounts of copper. An explanation for this depression is unknown. The results represent an average of six replications. Other than this early depression effect the growth curve for mustard as affected by copper is similar to that of most nutrients. Although mustard, because of its adaptation to greenhouse work, was the only plant used in this study, it would be reasonable to assume from the results of Allison, *et al*, (1) and others (15, 16, 17, 18, 19) that other crops would respond likewise.

The growth of mustard in relation to the absorption of copper as shown in Figs. 3, 4, and 5 indicate that the rate of growth with increased amounts of copper was less than that of the rate of absorption, the difference being in degree only. This is probably true for most nutrient salts.

The exact rôle of copper in these studies is not known, but it would be difficult to assign the function entirely to that of an oxidizing catalyst or neutralizer of toxins, especially with the results

in the wide variety of soil types. It is also doubtful that its stimulation in this study was due entirely to a fungicidal effect. There seems to be little doubt that its beneficial effects are internal in nature and could be classified as nutritive. The results of Anderson (2), Sommer (19), and others seem to confirm this viewpoint. While no positive evidence is available, it appears that copper is associated with the formation of plant hormones, possibly vitamins, or related compounds, yet not definitely known.

In view of the fact that only C. P. chemicals were used, it would be reasonable to assume that greater variation would have been obtained with purified chemicals.

SUMMARY

To summarize, the results indicate that copper has a nutritive value in the growth of mustard over a wide range of soil types, the greatest stimulation being obtained on soils of lowest productivity. The results also indicate that copper may be deficient on certain soil types in a manner similar to that of potash or phosphorus. The growth curve of mustard plants with varying amounts of copper appears to be similar to that of the more common nutrients.

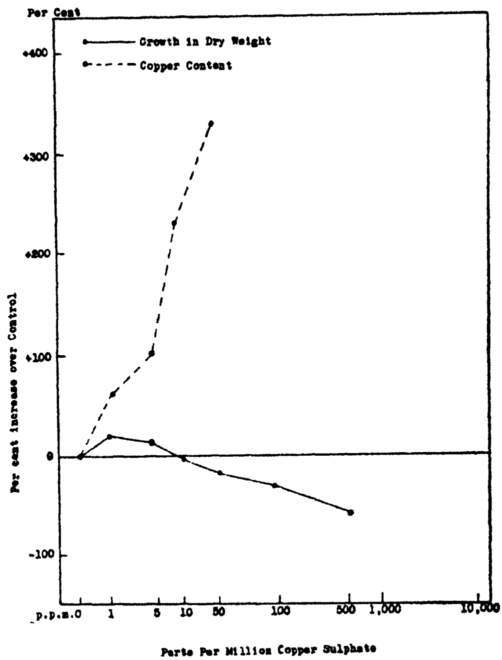

FIG. 4.—Increase of growth and copper content of mustard on Orangeburg sandy loam with varying amounts of copper sulfate.

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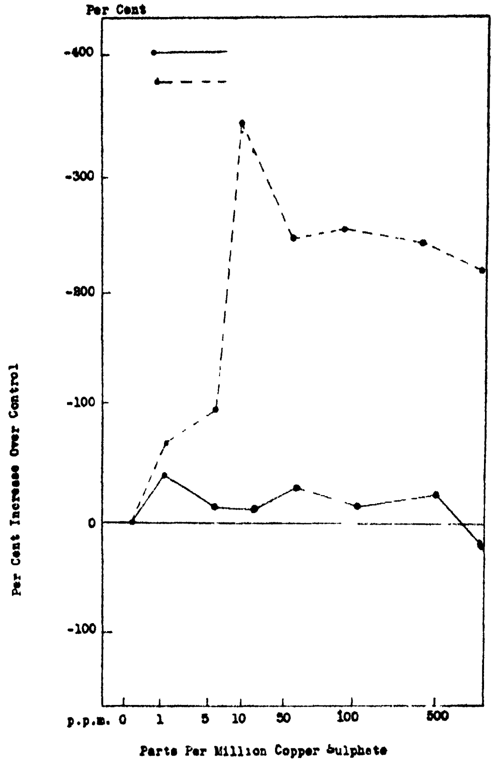

FIG. 5.—Increase of growth and copper content of mustard on Everglades peat with varying amounts of copper sulfate.

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THE EFFECT OF WATER-SOLUBLE AND TOTAL NITROGEN AND OF DRYING ON THE RATE OF NITRIFICATION OF SOME COMMON FLORIDA WEEDS[1]

M. R. BEDSOLE, JR.[2]

THE maintenance of soil organic matter is one of the major problems of cultivated land. This is especially true in Florida where climatic and soil conditions are conducive to rapid oxidation and loss of organic matter. Moreover, the varied farm practices in the state often limit the use of leguminous and other cover crops. Because of these conditions, it appeared advisable to investigate the green manure value of some of the more common weeds so abundant in many sections of the state.

One of the primary values of a green manure crop is the available nitrogen furnished during the process of decomposition. The higher nitrogen content of legumes, with a consequent greater rate of nitrification, justifies their use for this purpose.

The relationship between the nitrogen content of plants and nitrification has been pointed out by Waksman and Tenney (11),[3] Leukel, *et al.* (6), and others. However, information concerning the influence of the physical condition of the cover crops (drying) on decomposition is somewhat indefinite, even though it is a common practice to incorporate most cover crops into the soil in an air-dry condition.

Whiting and Schoonover (13) reported that the main effect of drying on the rate of decomposition was a change in the physical properties of the cells. Hutcheson and Milligan (5) place considerable importance on the content of moisture in the cells of the plant as favoring rapid nitrification.

The objects of the study reported here were (a) to compare the rate of nitrification of some common weeds and grasses in Florida with the important cover crops, and (b) to determine the effect of the total and water-soluble nitrogen and moisture in the cover crop on the rate of nitrate accumulation in the soil.

EXPERIMENTAL METHODS

The study was conducted under controlled conditions, using the standard beaker methods for determining the rate of nitrification. Norfolk fine sand with a reaction of pH 6.2 which had been passed through a 20-mesh screen was used in cultures of 500 grams of air-dry soil. The cover crops were harvested at bloom stage and chopped into small pieces before being incorporated with the soil at the rate of 1.5% green weight (or the equivalent dried at 85° C for 12 hours).

The cultures were run in duplicate and incubated at 30° C and 12% moisture. The nitrate nitrogen was determined by the phenoldisulfonic acid method (1) from a 1:3 soil-water extract.

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[3]Figures in parenthesis refer to "Literature Cited", p. 821.

The water-soluble nitrogen in the plants was determined by grinding 20-gram portions of plants in a mortar with clean quartz sand until thoroughly macerated. The material was then transferred to a beaker and 200 ml. of distilled water added. This was stirred frequently for 30 minutes and the solution filtered through four thicknesses of cheesecloth. The sand and plant material was then transferred back to the mortar and the above operation repeated. Finally, the mass of sand and macerated material was transferred to the cheesecloth filter and washed with an additional 250 ml. of distilled water. The combined filtrates and washings were diluted to a volume of 1 liter and the soluble nitrogen determined by the Kjeldhal-Gunning-Arnold method (1) from aliquats of this solution. The water-soluble nitrogen was also determined in the dried samples of crab grass, *Crotalaria spectabilis*, Spanish needle, wire grass, and natal grass.

The total nitrogen in the plants was determined by the usual methods of the Association of Official Agricultural Chemists (1). The results in all cases represent an average of duplicate determinations.

RESULTS

The results of this study are tabulated in Table 1. The weights of the different plants (whether green or dry) are expressed on the dry-weight basis under "dry matter equivalent." The relation between the total and water-soluble nitrogen in the plants and the rate of nitrification is shown in Fig. 1.

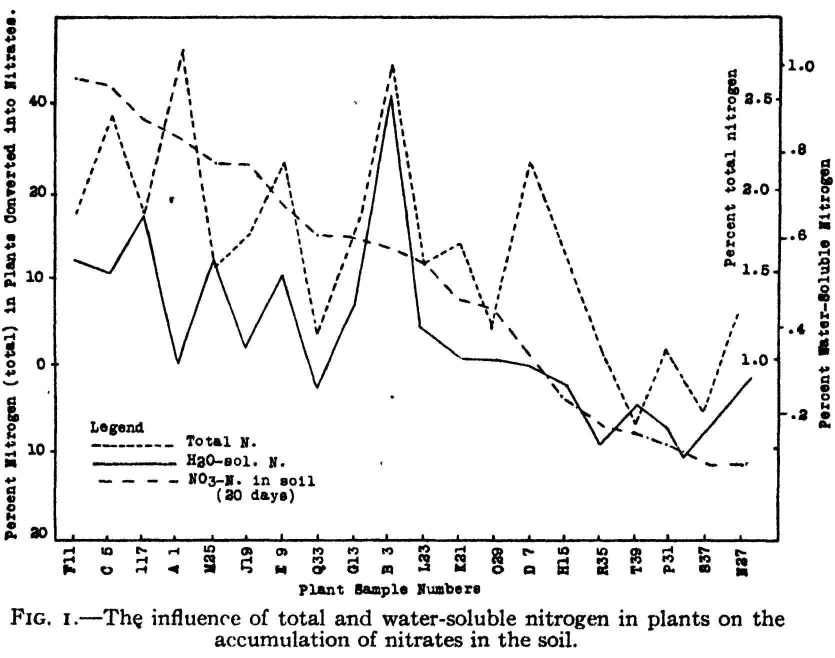

FIG. 1.—The influence of total and water-soluble nitrogen in plants on the accumulation of nitrates in the soil.

Control cultures were incubated under identical conditions of moisture and temperature as all the other cultures. Where the soil nitrogen was utilized by the organisms in decomposing plants of a high carbonaceous nature this reduction is indicated by a minus sign

under the column "gain over check." The untreated or central culture showed a concentration of 0.010 mgm nitrate nitrogen per gram of soil at the end of the 20-day period.

DISCUSSION

An examination of the data in Table 1 indicates that the nitrification of crops containing above 1.7% total nitrogen and as much as 0.5% water-soluble nitrogen is only slightly affected by drying, while plants containing less than 0.5% water-soluble nitrogen show a decrease in nitrification upon drying, even where the total nitrogen is above 1.7%. On the other hand, lespedeza and dog fennel, while containing above 1.7% total nitrogen but less than 0.3% water-soluble nitrogen, showed a depression on the rate of nitrification when dried.

Whiting and Schoonover (12) suggested that the shrinkage of the cell during drying retards the re-entrance of water, thereby preventing the soil organisms from readily attacking the materials in the cells. It seems equally probable that the rôle of water-soluble nitrogen is to stimulate bacterial activity through the more rapid solution and diffusion of available nitrogen. Consequently, those plants containing a relatively high content of water-soluble nitrogen would demonstrate the least depressive effect on drying. The results regarding the influence of high amounts of nitrogen on nitrification are in agreement with reports by Waksman (11) and others (13).

The fluctuations in the content of water-soluble nitrogen in either the high or low total nitrogen group appeared to exert some influence on the rate of nitrification. When the water-soluble nitrogen was above 0.5%. Nitrification was favorable, although the total nitrogen was below 1.7%. This was shown by Mexican clover. Since the water-soluble nitrogen in the low nitrogen group varies consistently with the total nitrogen, it is difficult to say which is more influential on nitrification, moisture or nitrogen.

Excluding sandburr, the nitrification of green material seems dependent upon a water-soluble nitrogen content of 0.33% or above, regardless of the total amount of nitrogen. On the average, the water-soluble nitrogen was higher in those plants containing more than 1.7% nitrogen, although there was considerable variation. However, as shown by Whiting and Schoonover (13), the water-extractable nitrogen is not always in direct proportion to the total nitrogen in sweet clover. It appears that a definite relationship exists between the water-soluble nitrogen in the dried cover crop and the rate of nitrate accumulation in the soil.

The results of Hutcheson and Milligan (5) indicate that water was probably the controlling factor in the decomposition and nitrification of green manures in the soil. They credit the high moisture content of green succulent materials with being a large factor in the nitrification, and explain the more rapid nitrification of succulent materials to this one factor. An examination of the data presented in Table 1 shows that there is no relation between the succulence or moisture content of the plant and the rate of nitrification. The column "dry matter equivalent" represents the residue after drying 7.5 grams of plant material for 12 hours at 85° C. Heck (3) reported a greater

TABLE 1.—*The effect of drying and of total and water-soluble nitrogen in some important cover crops and weeds on the accumulation of nitrate nitrogen in the soil.*

No.	Cover crop*	Physical condition of plants	Dry matter equivalent grams	Percentage of N		N added per gram of soil, Mgm.	Nitrate nitrogen in soil after incubation for 20 days		
				Total	Water-soluble		NO_3N per gram of soil, mgm.	Gain or loss over check, mgm	N Nitrified %
A 1	Cockleburr	green	1.32	2.76	0.33	0.073	0.0290	0.019	26.02
2	(*Xanthium* sp.)	dry	1.32	2.76	—	0.073	0.0260	0.016	21.91
B 3	Crotalaria	green	2.08	2 62	0.95	0.109	0.0240	0.014	12.84
4	(*Crot. Striata*)	dry	2.08	2.62	—	0.109	0.0220	0.012	11.00
C 5	Boerhaavia (small)	green	1.36	2.49	0.53	0.068	0.0320	0.022	32.35
6	(*Boerhaavia erecta*)	dry	1.36	2.49	—	0.068	0.0250	0.015	22.06
D 7	Lespedezia	green	3.25	2.19	0.28	0.142	0.0117	0.0017	1.19
8	(*Lespedezia striata*)	dry	3.25	2.19	—	0.142	0.0022	−0.0078	−5.49
E 9	Coffee weed	green	2.08	2.16	0.52	0.090	0.0260	0.0160	17.78
10	(*Cassia tora*)	dry	2.08	2.16	—	0.090	0.0250	0.0150	16.67
F 11	Beggarweed	green	1.85	1.87	0.57	0.069	0.0330	0.023	33.33
12	(*Meibomia tortuosa*)	dry	1.85	1.87	—	0.069	0.0380	0.0280	40.57
G 13	Careless weed	green	1.50	1.81	0.45	0.054	0.0181	0.0081	15.00
14	(*Amaranthus* sp.)	dry	1.50	1.81	—	0.054	0.0118	0.0018	3.33
H 15	Dog fennel	green	1 53	1 81	0.26	0.0555	0.0080	−0.0020	−3.63
16	(*Anthemis cotula*)	dry	1.53	1.81	—	0.055	0.0077	−0.0023	−4.18

I 17	Crab grass	green	1.50	1.78	0.67	0.053	0.0250	0.015	28.30
18	(*Synthorisma Simpsonii*)	dry	1.50	1.78	0.33	0.053	0.0270	0.017	32.07
J 19	Crotalaria	green	1.60	1.75	0.36	0.056	0.023	0.013	23.21
20	(*Crot. spectabilis*)	dry	1.60	1.75	0.46	0.056	0.009	-0.001	-1.80
K 21	Nut grass	green	1.96	1.61	0.34	0.063	0.0150	0.005	7.94
22	(*Cyperus rotundus*)	dry	1.96	1.61	——	0.063	0.0062	-0.0038	-6.03
L 23	Ironweed	green	2.38	1.58	0.39	0.075	0.0190	0.009	12.00
24	(*Centaurea Calcitrapa*)	dry	2.38	1.58	——	0.075	0.0139	0.0039	5.20
M 25	Mexican clover	green	1.00	1.55	0.57	0.031	0.0172	0.0072	23.22
26	(*Richardia scabra*)	dry	1.00	1.55	——	0.031	0.0168	0.0068	21.93
N 27	Sandburr	green	1.28	1.30	0.33	0.033	0.0072	-0.0028	-8.48
28	(*Cenchrus tribuloides*)	dry	1.28	1.30	——	0.033	0.0084	-0.0016	-4.84
O 29	Pepper grass	green	2.86	1.20	0.34	0.069	0.0144	0.0044	6.37
30	(*Lepidium virginicum*)	dry	2.86	1.20	——	0.069	0.0123	0.0023	3.33
P 31	Ragweed (small)	green	2.47	1.12	0.17	0.055	0.0050	-0.005	-9.09
32	(*Ambrosia artemis*)	dry	2.47	1.12	——	0.055	0.0020	-0.008	-14.54
Q 33	Spanish needle	green	1.85	1.18	0.26	0.044	0.0170	0.007	15.90
34	(*Bidens dispennata*)	dry	1.85	1.18	0.13	0.044	0.0050	-0.005	-11.35
R 35	Johnson grass	green	2.13	1.09	0.13	0.046	0.007	-0.003	-6.52
36	(*Sorghum halepense*)	dry	2.13	1.09	——	0.046	0.0051	-0.0049	-10.65
S 37	Wire grass	green	4.46	0.74	0.12	0.066	0.0030	-0.007	-10.60
38	(unclassified)	dry	4.46	0.74	0.08	0.066	0.0020	-0.008	-12.12
T 39	Natal grass	green	2.43	0.67	0.22	0.034	0.0070	-0.003	-8.82
40	(*Tricholaena rosea*)	dry	2.43	0.67	0.14	0.034	0.0030	-0.007	-20.58

*The nomenclature of plants was derived from the works of Small (9), Hitchcock (4) and Montgomery (7).

nitrification of *Aspergillus oryzae* tissue when dried at 65° C than when autoclaved. The high temperature probably changed the form of nitrogen in the fungus.

The depressing effect of nitrogen accumulation in the soil resulting from drying the plants becomes more pronounced with crops containing less than 0.5% water-soluble and 1.7% total nitrogen than with those possessing higher amounts of water-soluble and total nitrogen. The results indicate that the water-soluble nitrogen in *Crotalaria spectabilis* increases on drying, yet the drying seemed to depress the rate of nitrification. An explanation of this response is unknown.

The rate of nitrification of some common cover crops, i. e., *Crotalaria striata*, *Crotalaria spectabilis*, *Lespedeza striata*, beggarweed, and Natal grass, was found to be somewhat low. *Crotalaria striata* led the members of this group in nitrogen content, while Beggarweed led in the rate of nitrification. Although Natal grass has been shown to be a satisfactory cover crop in citrus groves (10) it has a rather doubtful value when followed by any quick-maturing crop because of its low nitrogen content. Its virtue consists more in the resistance of decomposition and loss than in nitrate accumulation on sandy soils.

The crops with less than 1.7% nitrogen, such as wire grass, pepper grass, sandburr, Spanish needle, and ragweed, show a slow rate of nitrate accumulation and would probably have a low value for immediate use in soils if available nitrogen was the limiting factor. Here again, it is the matter of resisting nitrification that has merit in sandy lands. However, Boerhaavia, coffeeweed, careless weed, cockleburr, and crab grass are naturally occurring weeds which contain sufficient amounts of nitrogen to make them adaptable for cover crop purposes. They are all volunteer crops, will fit into the different cropping programs, and their growth should be encouraged.

SUMMARY AND CONCLUSIONS

A number of weeds common to Florida were analyzed for water-soluble and total nitrogen. Also, the rate of nitrification was determined on these crops in both the green and dry stage, using Norfolk fine sand for cultures. The results may be summarized as follows:

1. Boerhaavia, coffeeweed, careless weed, and crab grass contain a comparatively high percentage of water-soluble and total nitrogen, and appear suitable for cover crop purposes where a rapidly nitrifying material is required.
2. Wire grass, pepper grass, sandburr, Spanish needle, and ragweed are low in total and water-soluble nitrogen and slow to yield available nitrates.
3. The water-soluble nitrogen content appears to be the most important factor involved in the nitrification of green and dried plants followed by total nitrogen and degree of hydration or moisture in the order named.
4. The nitrification of plants containing above 1.7% nitrogen and 0.5% water-soluble nitrogen is only slightly affected by drying, while plants containing less than 0.5% water-soluble nitrogen show

a decrease in nitrification upon drying, even where the total nitrogen content is above 1.7%.

5. If the water-soluble nitrogen is 0.5% or above, favorable nitrate accumulation occurs, even though the total nitrogen is less than 1.7%.
6. Plants containing above 1.7% total nitrogen but less than 0.33% water-soluble nitrogen have a slow accumulation of nitrate nitrogen in the soil.

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GERMINATION OF SEED OF FARM CROPS IN COLORADO AFTER STORAGE FOR VARIOUS PERIODS OF YEARS[1]

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THE knowledge that farm seeds maintain their viability over a long period of years may assist in solving the seed situation in years of drouth or of complete crop failure. Little is known of the viability of seeds after storage for several years under arid conditions. The data reported in this paper are from a study carried on with seeds stored for periods varying from 1 to 15 years.

The literature on storage of farm seeds was reviewed in a previous paper by the authors[3] and will not be discussed here. Previous results have shown that seeds of wheat, oats, and barley exhibit a gradual decline in germination rate for a 10-year period. At the end of this time their germination was approximately 10% lower than when 1 year old. Germination of Rosen rye and Wisconsin Black soybeans decreased more rapidly. About 10% of their original germination was lost in a 5-year period. Germination of Black Amber sorghum dropped only 2% in 6 years. Yellow dent corn germinated well for the first 5 years but decreased rapidly after the sixth year. The results reported in this paper are a continuation of the previous work reported by the authors.

EXPERIMENTAL METHODS AND RESULTS

The first tests were made on the 1920 crop. The grains were threshed, cleaned, and stored in 100-pound sacks, which were then placed in an unheated room. They were stored in the same room during the entire period of the test. Samples were taken in February of each succeeding year. Composite samples from each sack were made by mixing grain drawn from the sacks by a grain probe and by taking off a portion with a small scoop. Germination tests were made before July 1 of each year. Crops from the succeeding years, 1920–1929, were saved when grown and placed in the storage room. Only perfect seeds were used for germination, broken and damaged seeds being discarded. In the later years of the experiment considerable damage was done by the dermestid beetle (*Trogoderma tarsale*). All damaged seeds were discarded. The storage room was sprayed with an ethylene dichloride-carbon tetrachloride mixture to control insect pests.[4] The crops used were the standard varieties of cereals shown in Table 1.

[1]Contribution from the Colorado Agricultural Experiment Station, Fort Collins, Colo. Received for publication July 10, 1937.

[2]Agronomist and Seed Analyst, respectively.

[3]ROBERTSON, D. W., and LUTE, ANNA M. Germination of the seed of farm crops in Colorado after storage for various periods of years. Jour. Agr. Res., 45: 455–462. 1932.

[4]The mixture used was ethylene dichloride 3 parts, carbon tetrachloride 1 part by volume, according to Roark, R. C., and Cotton, R. T. Tests of various Alipathic compounds as fumigants. U. S. D. A. Tech. Bul. 162. 1929.

TABLE 1.—*Varieties of seed studied and years in which they were grown.**

Crop	Variety	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Spring wheat	Marquis		+	+	+	+	+	+	+		+
Winter wheat	Kanred		+			+					+
Spring wheat	Defiance			+		+		+	+		
Durum wheat	Kubanka		+	+							+
Oats	Colorado 37	+		+	+	+	+	+	+	+	+
	Great Dakota			+	+						
	Swedish Victory	+		+							
	White Russian	+									
	Gold Rain						+	+			
	Nebraska 21			+		+	+	+	+	+	+
Barley	Nepal	+	+	+	+	+	+				
	Success	+	+	+							
	Colsess			+	+	+	+	+	+	+	+
	Coast	+	+		+	+	+				
	Hanna	+		+							
	Gold	+									
	Moister						+	+	+		
Winter rye	Rosen			+	+	+				+	
Soybean	Wisconsin Black				+	+					
Sorghum	Black Amber						+	+	+		
Corn	Yellow dent		+	+	+	+					

*Plus mark signifies crop was grown in year indicated.

The average rainfall and relative humidity, "½ (7A + 7P)," in percentage of saturation are given in Table 2.[5] These data were taken from Bulletin No. 340 (Tables 17 and 21)[6] of the Colorado Agricultural Experiment Station.

TABLE 2.—*Rainfall and relative humidity during the period in which the crops were grown.*

Year	Average annual precipitation, in.	Average annual relative humidity, %
1920	11.65	70.2
1921	14.83	66.2
1922	9.98	67.6
1923	27.57	71.6
1924	10.64	64.8
1925	14.50	64.3
1926	13.56	66.4
1927	15.77	67.2
1928	13.54	65.3
1929	13.73	66.8
1930	15.17	64.8

[5]To obtain the relative humidity, readings were made twice daily at 7 a. m. and 7 p. m., and the average of the two readings taken as the mean.
[6]Data for 1928 to 1930 were obtained directly from Mr. R. E. Trimble.

There appears to be no connection between the average annual relative humidity and the original germination percentage. Humidities for all years were low. The actual percentage of moisture in the seed samples was determined for the 1929 crop and was found to range between 9.5 and 11.4%. No tests were made on the other crops.

The germination tests made the year the seeds were harvested ranged from 93.0 to 98.5% for Marquis, 84 to 90% for Kubanka, and 93 to 95% for Kanred wheat (Table 3). Barley and rye showed a greater variation from year to year and for different varieties. The germination percentage of oats did not differ greatly from that of wheat.

TABLE 3.—*Germination percentages for various crops harvested in different years.*

Variety	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
					Wheat					
Marquis	—	98.0	97.5	93.0	93.5	97.5	95.5	98.5	—	97.0
Defiance	—	—	96.0	—	89.0	—	90.5	98.5	—	—
Kanred	—	95.0	—	—	94.0	—	—	—	—	93.0
Kubanka	—	88.0	90.0	—	—	—	—	—	—	84.0
					Barley					
Nepal	87.0	95.5	95.0	73.0	69.0	84.0	—	—	—	—
Success	98.5	99.5	96.0	—	—	—	—	—	—	—
Colsess	—	—	99.5	98.5	97.0	97.0	94.0	97.0	97.0	99.5
Coast	97.0	94.0	—	98.5	92.0	96.5	—	—	—	—
Trebi	—	—	—	—	—	—	97.0	—	—	91.5
Hanna	90.5	—	96.0	—	—	—	—	—	—	—
Gold	95.5	—	—	—	—	—	—	—	—	—
Moister	—	—	—	—	—	98.5	96.0	97.0	—	—
Elfry	—	—	—	—	—	99.5	—	—	—	—
Smyrna	—	—	—	—	—	—	—	91.5	—	—
					Oats					
Colorado 37	98.0	—	99.0	99.0	98.0	97.0	97.0	95.0	98.5	98.0
Nebraska 21	—	—	97.0	—	97.5	95.5	94.0	98.0	—	92.0
Swedish Victory	99.0	—	99.5	—	—	—	—	—	—	—
Gold Rain	—	—	—	—	—	95.5	97.0	—	—	—
Great Dakota	—	—	99.5	99.0	—	—	—	—	—	—
					Miscellaneous Crops					
Rye	—	—	98.0	83.5	84.0	—	—	—	—	83.5
Soybeans	—	—	—	93.5	—	—	—	—	—	—
Sorghums	—	—	—	—	—	—	—	62.0	—	—
Corn	—	—	—	85.0	98.0	—	—	—	—	—

The general trend seems to indicate that oats, covered barley, and Marquis and Kanred wheat have a high percentage of germination the first year, while Kubanka wheat, Nepal barley (naked), and rye show a lower germination percentage the first year.

A study of the germination of wheat, oats, and barley as a percentage of the original germination shows that when all varieties of the same crop are averaged there is a slow decline in germination percentage (Fig. 1) for the first 10-year period with a sharp break in germination between the tenth and twelfth years.

In Fig. 1, the number of crops per year varies. The points on the curve for wheat represent 18 crops for the first 7 years and drop off to 3 crops in the fifteenth year (Table 4). The points on the curve for barley represent from 26 to 32 crops for the first 10 years, and drop to 8 crops in the fifteenth year (Table 4). The points on the oat curve

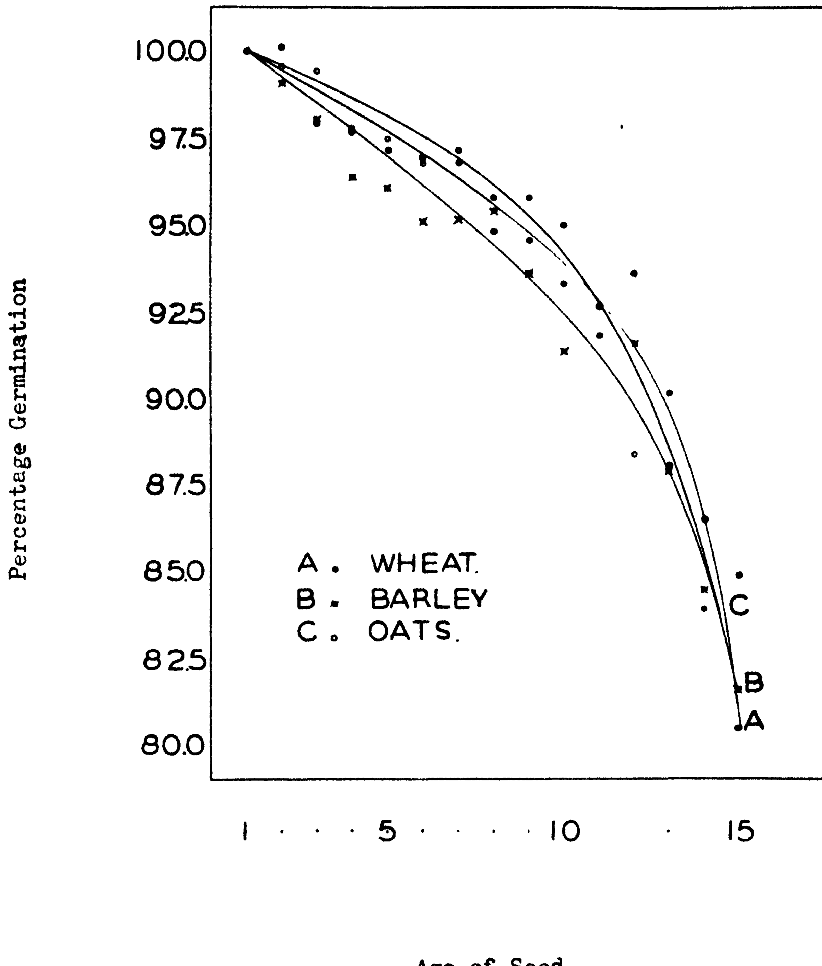

FIG. 1.—Curves showing the relationship between age of seed in years and percentage germination.

represent 15 or 16 crops for the first 8 years and drop off to 3 crops in the fifteenth year. The small number of crops from the tenth to the fifteenth year lessen the value of the data from the older seeds, but sufficient crops are used to indicate that a break in the viability occurs between the tenth and fifteenth years.

In presenting the data in Table 4, all germination percentages were calculated as a percentage of the first year. This accounts for the ap-

TABLE 4.—*Percentage germination and number of crops tested in indicated number of years after harvest.*

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
							Wheat								
Marquis C. I. 3641															
Germination %. . . .	100	99.8	98.2	96.0	97.0	96.5	95.4	94.5	95.5	95.5	92 0	93.4	90.1	87.5	83.7
Crops tested, number	8	8	8	8	8	8	8	7	7	6	5	4	3	2	1
Defiance															
Germination, % . . .	100	98.4	99.3	98.2	97.3	97.0	98.7	96.5	97.4	95.4	93 4	95.4	93.2	84.4	—
Crops tested, number.	4	4	4	4	4	4	4	4	4	3	2	2	1	1	—
Kanred C. I. 5146															
Germination % . . .	100	102.5	98.4	101.4	97.5	98.3	97.0	94.5	95.3	99.2	93.4	96.1	84.2	85.3	73.7
Crops tested, number.	3	3	3	3	3	3	3	2	2	2	2	2	1	1	1
Kubanka C. I. 1440															
Germination %. . .	100	100.6	94.5	97.5	97.5	97.7	98.1	92.5	84.9	88.8	93.0	89.7	84.4	87.1	84.1
Crops tested, number	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1
Average germination of all wheat %.	100	100.1	97.9	97.7	97.2	97 0	96.8	94.8	94.6	95.0	92.7	93.6	88.1	86.5	80.5
Total number of wheat crops tested.	18	18	18	18	18	18	18	15	15	13	11	10	7	6	3
Standard error of mean.	0.970	0.673	0.877	1.024	0.919	1.010	1.290	0.926	1.458	1.477	1.407	1.754	2.862	2.366	3.402
							Barley								
Nepal C. I. 595															
Germination %.	100	99.3	89.8	86.2	88.3	85.9	90.4	93.4	89.1	86.5	93.7	91.9	85.2	77.2	73.9
Crops tested, number.	6	6	4	6	6	6	6	6	6	6	6	5	4	3	2
Success															
Germination %.	100	97.8	95.3	97.0	98.5	94.1	96.4	94.9	89.8	91.5	89.6	89.6	90.2	89.2	89.9
Crops tested, number.	3	3	1	2	2	3	3	3	3	3	3	3	3	3	2
Colsess C. I. 2792															
Germination %.	100	98.5	98.0	98.5	97.6	97.9	97.2	97.7	96.9	97.1	94.3	92.9	94.0	94.5	—
Crops tested, number.	8	8	8	8	8	8	8	7	6	5	4	3	2	1	—
Coast															
Germination %.	100	100.5	100.1	99.6	98.6	98.8	98.3	98.4	98.2	97.9	97.1	97.6	96.9	98.9	95.8
Crops tested, number.	5	5	5	5	5	5	5	5	5	5	5	4	3	2	2

Trebi C. I. 936															
Germination %...	100	96.1	100.7	97.0	101.9	99.8	99.1	93.8	95.9	96.9	—	—	—	—	—
Crops tested, number	2	2	2	2	2	2	2	1	1	1	—	—	—	—	—
Hanna															
Germination %.....	100	97.2	104.2	99.0	100.4	94.9	90.2	90.8	90.7	86.6	87.1	84.1	80.8	76.5	67.4
Crops tested, number	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1
Gold C. I. 1145															
Germination %	100	97.4	99.5	98.4	93.7	87.4	81.0	79.1	78.0	68.1	74.9	84.3	66.5	69.1	66.0
Crops tested, number	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Moister C. I. 2799															
Germination %	100	99.8	99.3	99.6	95.6	97.6	96.1	96.3	96.4	88.5	87.3	—	—	—	—
Crops tested, number	3	3	3	3	3	3	3	3	3	2	1	—	—	—	—
Elfry C. I. 2800															
Germination %......	100	100	99.0	96.5	89.4	95.0	94.5	93.0	92.5	91.5	88.4	—	—	—	—
Crops tested, number	1	1	1	1	1	1	1	1	1	1	1	—	—	—	—
Smyrna															
Germination %	100	106.6	102.7	106	104.9	104.9	102.7	103.8	102.7	—	—	—	—	—	—
Crop tested, number	1	1	1	1	1	1	1	1	1	1	—	—	—	—	—
Average germination of all barley %	100	99.1	98.1	96.4	96.1	95.1	95.2	95.4	93.6	91.4	92.1	91.6	87.9	84.5	81.6
Total number of barley crops tested ...	32	31	28	31	31	32	32	30	29	26	23	18	15	12	8
Standard error of mean	1.243	0.628	0.910	1.317	1.214	1.304	1.796	1.669	1.697	2.376	2.143	3.079	2.437	3.326	4.790
Average germination of all naked barleys %	100	99.3	89.8	86.2	88.3	85.9	90.4	93.4	89.1	86.5	93.7	91.9	85.2	77.2	73.9
Total number of crops of naked barley tested.........	6	6	6	4	6	6	6	6	6	6	6	5	4	3	2
Average germination of all 6-row covered hooded barleys %	100	98.3	97.7	98.2	97.8	96.9	96.9	96.8	94.5	95.0	92.3	91.3	91.7	90.5	89.9
Total number of crops of 6-row covered hooded barleys tested........	11	11	9	10	10	11	11	10	9	8	7	6	5	4	2
Average germination of all 6-row covered awned barleys %	100	99.5	100	98.9	97.5	98.3	97.5	96.8	96.9	95.0	94.4	97.6	96.9	98.9	95.8

TABLE 4.—*Concluded.*

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
							Barley								
Total number of crops of 6-row covered awned barleys tested.	11	11	11	11	11	11	11	10	10	9	7	4	3	2	2
Average germination of all 2-row covered awned barleys tested %.	100	98.4	102.6	100.6	99.8	95.5	91.0	91.1	90.5	80.4	83.0	84.1	76.0	74.0	66.7
Total number of crops of 2-row covered awned barleys tested. .	4	3	4	4	4	4	4	4	4	3	3	3	3	3	2
							Oats								
Colorado 37															
Germination %.	100	100.1	99.4	98.0	97.6	97.2	98.6	95.5	97.5	95.4	93.3	89.1	88.2	84.3	80.6
Crops tested, number.	9	8	9	9	9	9	9	8	7	6	5	4	3	2	1
Nebraska 21															
Germination %.	100	100.6	99.1	98.4	98.6	98.3	97.9	96.2	95.7	93.6	86.2	84.9	—	—	—
Crops tested, number.	6	6	7	7	6	7	7	6	5	3	3	2	—	—	—
Swedish Victory															
Germination %.	100	95.0	99.3	97.8	93.5	92.7	94.5	92.7	91.0	88.7	93.2	88.4	92.5	87.4	85.9
Crops tested, number.	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1
Gold Rain															
Germination %	100	99.5	99.9	97.1	98.5	96.6	97.1	99.5	98.4	100.3	92.1	—	—	—	—
Crops tested. number.	2	2	2	2	2	2	2	2	2	2	1	—	—	—	—
Great Dakota															
Germination %.	100	97.8	97.8	95.7	96.5	94.8	93.0	95.5	91.9	86.7	93.5	90.2	88.2	81.4	—
Crops tested, number.	2	2	2	2	2	2	2	2	2	2	2	2	2	1	—
White Russian															
Germination %.	—	98.5	—	97.0	98.0	95.0	93.5	94.5	97.5	88.0	95.0	89.5	95.5	78.5	88.0
Crops tested, number	—	1	—	1	1	1	1	1	1	1	1	1	1	1	1
Average germination of all oats %.	100	99.6	99.2	97.8	97.5	96.8	97.2	95.8	95.8	93.3	91.8	88.4	90.2	83.9	84.8
Crops tested, number.	21	20	22	23	22	23	23	21	19	16	14	11	8	6	3

Standard error of mean	0.43	0.69	0.62	0.78	0.82	0.83	0.87	0.89	0.93	1.61	1.49	0.94	1.49	1.76	2.20
Average germination of all midseason oats %	100	99.2	99.2	97.5	97.1	96.1	96.9	95.6	95.9	93.2	93.4	89.2	90.2	83.9	84.8
Crops tested, number	15	14	15	16	16	16	16	15	14	13	11	9	8	6	3
Average germination of all early oats %	100	100.6	99.1	98.4	98.5	98.3	97.9	96.2	95.7	93.6	86.2	84.9	—	—	—
Crops tested, number	6	6	7	7	6	7	7	6	5	3	3	2	—	—	—
Winter Rye															
Rosen Rye															
Germination %	100	98.3	98.4	92.9	91.4	89.4	83.5	79.3	72.2	70.7	58.6	43.6	25.9	8.2	—
Crops tested, number	4	3	4	4	4	4	4	3	3	3	3	3	2	1	-
Soybeans															
Wisconsin Black															
Germination %	100	101.1	93.0	86.6	90.1	83.3	61.2	47.0	42.0	47.1	20.7	10.9	5.3	—	—
Crops tested, number	1	2	2	2	2	2	2	2	2	2	2	2	1	—	—
Black Amber															
Germination %	100	117.0	112.6	115.8	117.2	116.5	120.5	117.9	119.4	106.0	100	—	—	—	—
Crops tested, number	1	2	3	3	3	3	3	3	3	2	1	—	—	—	—
Corn*															
Germination %	92.0	90.0	97.0	97.0	87.0	88.4	86.9	78.0	80.4	69.6	65.5	64.1	48.0	54.7	36.0
Crops tested, number	2	1	2	2	3	5	6	6	5	6	5	6	5	3	1

*Actual germination percentages.

parent increase in germination percentage in some of the varieties. The standard error was calculated from the actual percentage germination for the first year and from the calculated percentages for the other years. The results from the corn crop give actual germination throughout. The same is true for White Russian oats. Unfortunately, germination tests were not obtained the first year on some of the corn and on White Russian oats, so calculations could not be made on a basis of 1-year-old seed.

WHEAT VARIETIES

The percentage germination of the various crops is given in Table 4. As previously mentioned, the number of crops tested drops off as the crops increase in age. This is due to the fact that they were produced in different years over a 10-year period. The fact that fewer crops are available as they advance in age may have some influence on the value of the data from the older crops. However, the trend seems to be consistent for all crops tested. Three varieties of *Triticum vulgare* and one variety of *T. durum* are represented in the table. When we consider the average germination of all wheat varieties tested, it will be noted that the germination drops slightly each year until the twelfth year and then takes a marked drop. This is also shown in Fig. 1. When we consider the drop in germination percentage by 5-year periods, it will be noted that there is a decline of 2.8% for the first 5-year period, 2.0% for the second 5-year period, and 14.5% for the third 5-year period.

The different varieties when analyzed separately show a similar trend and do not present any marked varietal difference for the first 15 years.

The actual germination of all wheat varieties tested is given in Table 5. This table represents the types of data obtained with the barley and oats studied in the germination experiment.

BARLEY VARIETIES

The results of the tests of barley varieties are shown in Table 4. The average germination of all barleys in percentage shows a gradual decline for the first 12-year period with a sharp drop between the twelfth and fifteenth years. This is shown graphically in Fig. 1. When the germination data are examined in 5-year periods, it will be seen that there was a drop of 3.9% for the first 5 years, 4.7% between the fifth and tenth years, and 9.8% between the tenth and fifteenth years.

The 6-row covered hooded barleys show a gradual decline for the first 10 years, dropping about 5%. The drop for the next 5 years is sharper, the varieties losing 5.1% between the tenth and fifteenth years.

The 6-row covered awned barleys lost about 5% in viability in the 15-year period for the varieties tested. The 6-row naked barleys show a somewhat sharper decline. The drop in germination for the first 5 years was 11.7%. The next 5-year period, however, showed very little decline, losing only 1.8%. This percentage held rather uniformly until the fourteenth year, when there was a sharp drop of about 8%.

TABLE 5.—*Germination percentage of different varieties of wheat grown at Fort Collins, Colorado, from 1921–1930.*

Years grown	Percentage of germination in indicated number of years after harvesting														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
							Marquis								
1921	98.0	97.0	96.0	92.5	93.5	92.5	94.5	88.5	94.0	89.5	84.5	82.5	81.0	77.0	82.0
1922	97.5	97.5	99.0	98.5	97.0	97.5	93.0	94.0	88 5	91.5	95.0	93.0	95.0	94.0	—
1923	93.0	94.5	83.0	81.5	86.5	79.0	84.0	86.0	91.0	92.5	84.5	87.0	84 0	—	—
1924	93.5	96.5	96.5	93.5	95.0	92.5	95.0	93.5	90.5	96.0	92.0	94.0	—	—	—
1925	97.5	93.5	94.5	87.5	88.5	95.0	81.5	85 0	89.0	83.0	85.0	—	—	—	—
1926	95.5	96.5	93.0	95.0	95.5	93 0	95.5	93.0	94.0	96.0	—	—	—	—	—
1927	98.5	96.5	99.0	98.5	97.0	98.5	97 0	96.5	96.0	—	—	—	—	—	—
1929	97.0	96.5	96.0	93.0	94.5	96.0	94.0	—	—	—	—	—	—	—	—
							Kanred								
1921	95.0	97.0	94.0	95 5	93 5	92.5	88.0	89.0	86.0	93.5	84.5	85.5	80.0	81.0	70.0
1924	94.0	95.0	91.5	94 5	91.0	90 5	90 5	89.5	94 5	94.0	92.0	96.0	—	—	—
1929	93.0	97.0	92.0	96.0	90 5	94.0	95.0	—	—	—	—	—	—	—	—
							Defiance								
1922	96.0	95.0	96 0	94.0	95.0	94.0	95 0	92.5	90.5	92.0	94.0	93.5	89.5	81.0	—
1924	89.0	91.0	88.5	91.5	89.5	87.0	83.0	86.0	92.5	84.0	79.0	83 7	—	—	—
1926	90.5	86.0	90 5	85.5	82.0	84.0	95.0	87.0	86.0	87.0	—	—	—	—	—
1927	98.5	96.0	96.5	96.0	97 5	98.0	96.0	95.5	95 0	—	—	—	—	—	—
							Kubanka								
1921	88.0	92 5	86.5	89.5	88.5	91.5	86.0	84.5	79.0	79.0	83.0	80.5	82.0	76.0	74.0
1922	90.0	86.5	87.5	84.0	80.5	84.0	81.5	80.0	72.0	79.0	82.5	79.0	68.0	79.0	—
1929	84.0	84.5	74.0	82.0	86.0	80.5	89.0	—	—	—	—	—	—	—	—

The 2-row covered barleys show a high germination for the first 5-year period. In the second 5-year period there is a drop of 19.4%; however, 10% of this drop is accounted for in the tenth year. From the tenth to the fifteenth year there is a sharp decline with a loss of 13.7% for the 5-year period.

The barleys tested seem to show some varietal differences, the hulless variety, Nepal C. I. 595, falling off in germination much more quickly than the hulled varieties. The 2-row hulled varieties drop off much quicker from the tenth to the fifteenth year than either of the 6-row hulled groups.

OAT VARIETIES

Both midseason and early oats are included in the tests. Only varieties of *Avena sativa* and *A. sativa orientalis* were included in the experiment. Colorado 37 oats show a drop of 2.4% germination in the first 5 years of the test, 7.2% from the fifth to the tenth year, with a rather sharp drop of 14.8% from the tenth to the fifteenth year. Swedish Victory and Great Dakota, the other two white midseason oats, lose about 10% in germination in the first 10-year period and drop off about 5% between the tenth and fifteenth years. Gold Rain, a yellow oat with a shorter growing period than the midseason varieties, loses very little in germination ability in the first 10-year period, but drops off sharply in the eleventh year. Nebraska 21, the only representative of the early oats, behaved very much like the midseason oats for the period it was tested. White Russian, the only side oat tested, behaves similarly to the other oat varieties. The average germination of all oats tested shows a similar trend to that found for wheat and barley. The germination drops off gradually for the first 10-year period, with a sharp break in germination between the twelfth and thirteenth years.

OTHER SEEDS

The data obtained on the other crops are less complete and the number of crop years per variety are less. However, the data obtained should give some indication of the behavior of the crops tested under arid conditions when stored in sacks. The germination percentages for Rosen rye, Wisconsin Black soybeans, and yellow dent corn are plotted in Fig. 2. The curves show a similar trend to those for wheat, barley, and oats. However, the break in the germination occurs much sooner for these crops. The results from the Black Amber cane tests were not plotted since they do not yet show a decline in germination.

The germination tests (Table 4) for rye indicate a rather sharp drop after the third year, with a slight decline for 3 years more. Between the sixth and seventh years there is a sharp drop which continues for the rest of the test. The final germination at the end of 14 years is 8.2% of the original germination percentage. Rosen rye evidently loses its viability more quickly than any of the varieties of wheat, oats, or barley tested.

The Black Amber cane showed an increase over the first year for all years except the 1925 sample. Many lots of amber cane, the year harvested, fail to germinate completely in 6 days and, undoubtedly, this accounts for the increase over the first year's test. The high germination was maintained for the first 10 years of the test. There is a slight drop in the eleventh year, but only one crop is included and further tests are needed before the final trend can be determined.

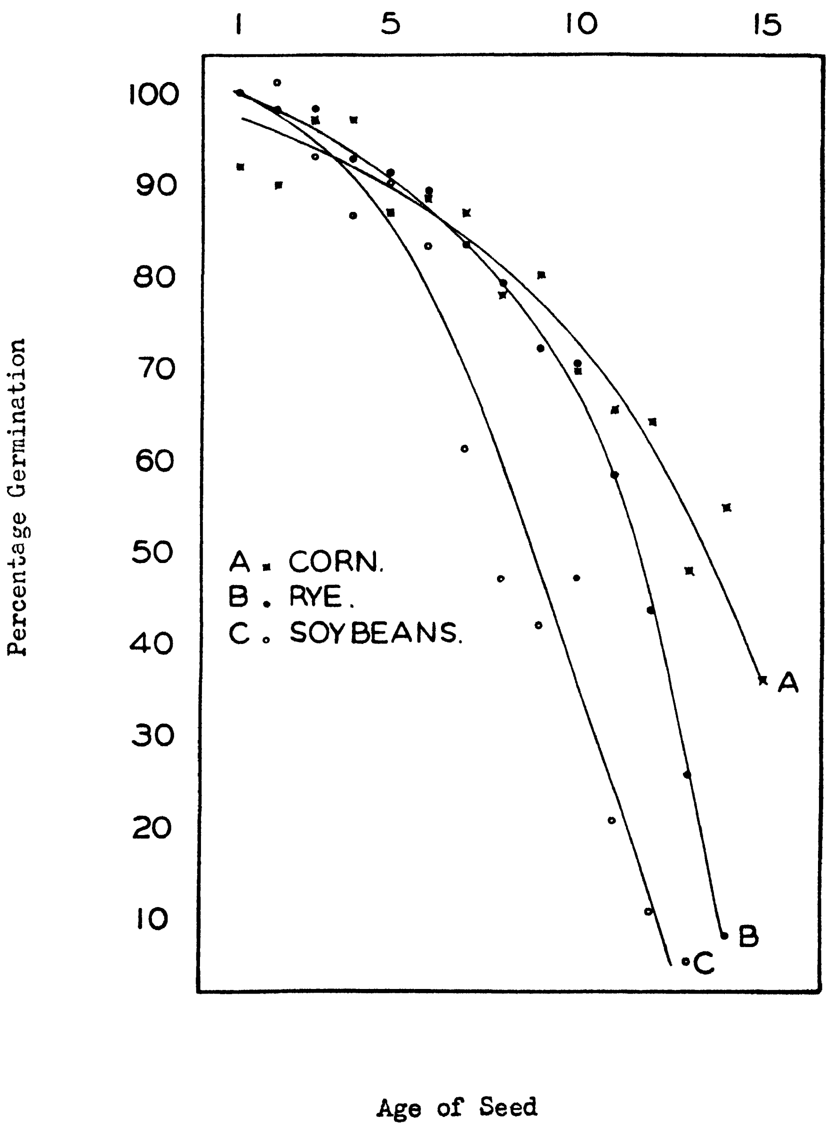

FIG. 2.—Curves showing the relationship between age of seed in years and percentage germination for corn, rye, and soybeans.

The samples of corn are incomplete as will be seen from the records of the number of crops grown; however, the data indicate that the germination does not decrease appreciably for the first 5-year period. The drop in the second 5-year period is 18.4%. Most of this occurs in the tenth year. From the tenth to the fifteenth year the drop is 33.6%.

The viability of Wisconsin Black soybeans dropped more quickly than in the other crops. A drop of 10% is found in the first 5-year period, followed by a drop of 42.9% in the second 5-year period. The drop in the final 3-year period is very marked, the final germination being only 5.3% of the original.

SUMMARY

Germination tests were made on the seeds of various farm crops adapted to Colorado conditions which had been stored in a dry, unheated room for periods varying from 1 to 15 years.

The germination percentage of wheat, oats, and barley declined slowly for the first 10-year period with a sharp break in germination between the tenth and twelfth years.

The drop in germination was as great or greater from the tenth to the fifteenth year as it was from the first to the tenth year.

There were indications of different reactions to storage between 6-row hulled, 2-row hulled, and 6-row hulless barleys.

Rosen rye and Wisconsin Black soybeans did not maintain their viability to the same degree as wheat, oats, and barley. The trend, however, was the same. The break occurred between the sixth and eighth years and dropped off very rapidly afterward.

Black Amber sorghum still maintained an excellent germination percentage after being stored for 10 years.

Yellow dent corn germinated well for the first 6 years and dropped off rapidly between the ninth and tenth years and again between the twelfth and thirteenth years.

The germination percentage of Rosen rye, Wisconsin Black soybeans, and corn was low at the end of the period of the test.

PRELIMINARY REPORT OF A STUDY ON METHODS USED IN BOTANICAL ANALYSES OF PASTURE SWARDS[1]

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THE recent impetus which has been given to research on pasture improvement in the United States by various educational and research agencies has stimulated an interest in improved methods for quantitative and qualitative analyses of pasture swards. A number of methods for evaluating pastures have been described in American and foreign literature, the applications of which are confined to an analysis of particular types of grassland and to the gathering of specific information. Hanson (5)[3] has compared different methods for determining botanical composition of the western North Dakota prairie. His conclusions apply, however, only to the type of vegetation characteristic of the region. Several of the methods now in use in the British Isles and New Zealand are adaptable to the types of sward which are found in the Great Lakes and New England regions. These methods differ in principle which makes it difficult to select, without considerable study, the most useful one for the particular pasture conditions. Some are meritorious in measuring productivity, composition, or quality of the sward with no one method apparently possessing all the qualities that may be desired. The need for an accurate and rapid quantitative method which will measure, without personal bias or error, the relative frequency and productivity of the pasture components in the types of sward found in the humid region of the eastern and middle western states has resulted in the pasture methodology herein reported. It is not possible to collect sufficient data in one season to warrant final evaluation of all the methods. The apparent demand for information as to the efficiency and practicability of the different methods seems to justify a preliminary report of the research now in progress.

PROCEDURE

The study of methods is being done on two of a series of fields in a comprehensive pasture project on the University of Wisconsin Experiment Station farm at Madison, Wisc. (1). One of the fields is treated annually with commercial nitrogen and the other is left untreated as a check. The two fields, each consisting of 4½ acres, were sown in 1934 to the following mixture: 14 pounds per acre Kentucky bluegrass (*Poa pratensis*), 10 pounds timothy (*Phleum pratense*), 4 pounds redtop (*Agrostis alba*), 2 pounds white clover (*Trifolium repens*), 3 pounds alsike clover (*Trifolium hybridium*), and 3 pounds red clover (*Trifolium pratense*). A series of 30 randomized counts for each method were taken on each field during May and

[1]Cooperative investigations of the Wisconsin Agricultural Experiment Station and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Paper No. 122 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Excellent assistance in these studies was provided by Mr. Paul Ozanne and Mr. Gilbert Ahlgren. Received for publication July 6, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 840.

again in October 1936. Two men working together comprised a crew, one identifying the species and the other recording. Three crews making the counts were so organized that one crew counted at only 10 of the 30 stations. The average time required to make determinations by each method was obtained from preliminary trials and each method was, as far as possible, placed on a comparable time basis in order to measure the relative efficiency.

Fisher's (4) analysis of variance was applied to the data for each method (Table 1). A summation of the plant counts was used in the analysis, except for the data taken by the percentage area method which was read in the field as percentages. Both fields were divided into three paddocks of 10 stations each. Counts from each of the 10 stations were summarized and treated in the present analysis as a single replicate. The recommendations which follow are based on (a) accuracy as expressed by the F value, (b) amount of labor involved, and (c) specific information that can be obtained from the data.

TABLE 1.—*The F values for species determined by the different methods for making vegetative analyses of pastures.**

Method					
String	Specific frequency	Percentage frequency	Percentage area	Vertical point quadrat	Inclined point quadrat
May					
125.0	114.0	87.3	134.1	206.9	—
3.32†	3.32	3.32	3.07	3.07	—
October					
59.2	—	—	71.0	137.4	163.1
3.32	—	—	3.07	3.07	3.07

*Data obtained from 30 randomized stations on each of two 4½-acre fields.
†One per cent point.

DESCRIPTION AND APPLICATION OF METHODS STUDIED

STRING METHOD

The method is a modification of the one developed by Stone and Fryer (7) at the University of Alberta. It consists of counting all the plants of each species whose crowns (not leaves or stems) are vertically beneath or touching a string 36 inches long stretched tightly between two stakes. The method is essentially one of percentage frequency, and it gives no definite information as to the productivity or quality of the sward. It has the advantage of eliminating personal error and of not being excessively tedious. The analysis of our data indicates that it is one of the best methods for measuring rapid changes in the floristic composition of the pasture, particularly swards which have been newly seeded.

SPECIFIC FREQUENCY METHOD (3)

A square grid or frame, divided by cross wires into 25 5-cm squares, is used to record the presence of each species (not number of plants)

in each square. The method is comparatively rapid, and it may be used for a general survey of vegetation. Its use as a standard method, however, is questionable. It is of little value in vegetation which is over 3 inches tall. The only information that is to be obtained from the data is the relative frequency of one species to another. Two species, if evenly distributed over the area examined, will have the same specific frequency, although actually the productivity of one may be twice as great as the other.

PERCENTAGE FREQUENCY METHOD (2)

The method is similar to the specific frequency method, and in the present investigation the same frame was used, except that the crowns of plants of each species were counted in each of the 5-cm squares. In order to make the time necessary for making one reading comparable to other methods the vegetation was counted in 5 of the 25 5-cm squares. The information which can be obtained from these data is similar to that which can be obtained by other and easier methods.

PERCENTAGE AREA METHOD (3)

Two different frames were used, one with inside dimensions of 50 cm x 50 cm divided into 25 10-cm squares; the other with inside dimensions of 25 cm x 25 cm divided into 25 5-cm squares. In each of the 10- or 5-cm squares the percentage area covered by each species and the percentage of bare ground is estimated. The chief objection to the method lies in the apparent inability of the observer to estimate consistently the percentage of area covered by each species in different types of swards. The method fails if the vegetation is sufficiently tall to be displaced or affected by placing the frame upon the sward. The method has the advantage of covering a relatively large area, and it has been found by many who have used it to give reliable information.

POINT QUADRAT METHODS

The original point quadrat method was devised and used by Levy (6) in agrostological investigations in New Zealand. The apparatus consists of two horizontal pipes, mounted on legs 12 inches high, with a linear row of 10 holes spaced 2 inches apart through which needles 14 inches long are moved up and down (Fig. 1A).

The principle of the method is based on the mathematical concept that a point represents a unit area, *i. e.*, the limiting value of an area becoming progressively smaller is a point. In reality, therefore, the point quadrat method records at each station the vegetation at linearly arranged unit areas or "point quadrats."

As the method has been used, the needles were arranged to move vertically up and down or at right angles to the ground surface. Certain objections which can be made to that arrangement were overcome by setting the needles at an angle of 45 degrees. For convenience we refer to the two methods as the "Vertical Point Quadrat" and "Inclined Point Quadrat" methods, respectively.

VERTICAL POINT QUADRAT METHOD

The method has been used in the past in two ways both of which have been studied in the present investigation. First, (3), each needle is pushed down towards the vegetation until the point comes in contact with some part of a plant and a "hit" is recorded. Thus, at a single station 10 hits are recorded, each corresponding to a needle irrespective of whether the same plant was hit by one or several needles. If the point of a needle failed to touch a plant, the hit is recorded for bare space. The disadvantage of the method when it is used in the above manner is the tendency for the tall plants to be hit by the needles more frequently than the low prostrate ones.

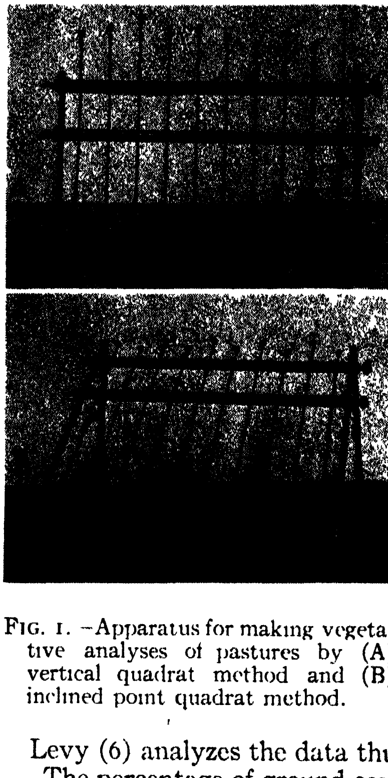

FIG. 1. —Apparatus for making vegetative analyses of pastures by (A) vertical quadrat method and (B) inclined point quadrat method.

The second application of the method (6) overcomes, in part, the above objection. By pushing each needle to the ground, and recording the number of times each species is hit during the downward movement, the shorter plants are placed on a parity with the taller ones. In this way all of the plants that are in the path of the needle are recorded.

Levy (6) analyzes the data thus obtained to express the following:

. The percentage of ground covered by each species by taking from the data the number of times a *species is hit* (not the number of plants of each species) per 100 readings (needles) and expressing it directly as a percentage.

Example 1.—Assumptions:

1. No species is hit more than once by a single needle, but any needle may hit a number of different species.
2. Bluegrass was hit 52 times, timothy 30, redtop 12, red clover 3, and bare space 8.

By expressing these quantities directly as percentages, the percentage of ground covered by each species is obtained. Since a needle in a single trial may hit more than one species, the total number of hits may equal more than 100, as in the above example 105 hits were made.

B The percentage of cover each species is contributing to the total area. These figures are obtained by taking the data used in A and applying the following formula:

$$\frac{\text{(Number of times a species is hit per 100 readings) x (100–bare space)}}{\text{Total number of times vegetation is hit per 100 readings}}$$

Example 2.—Accordingly,

$$\text{Kentucky blue grass} = \frac{52 \times (100-8)}{105-8} = 49.3\%$$

Similarly, timothy = 28.5%, redtop = 11.4%, red clover = 2.8%, plus 8% bare space totals 100%

C. The relative frequency of each species in the pasture sward. The data to be used is obtained by totaling the number of *plants* of each species hit irrespective of whether the needle hit the same plant more than once or different plants as it passes through each vegetative storey. The total number of times plants of each species is hit per 100 readings gives the relative frequency of each species.
Example 3.—Assumptions:
  1. Kentucky bluegrass was hit 80, timothy 46, redtop 15, red clover 9, total 150. These quantities are taken to express the relative frequency of each species.

D. The percentage that each species is contributing to the pasture sward. These figures are obtained by taking the data used in C and applying the formula:

$$\frac{\text{Total number of times plants of each species is hit x 100}}{\text{Total number of times vegetation is hit}}$$

Example 4.—Accordingly,

$$\text{Kentucky bluegrass} = \frac{80}{150} \times 100 = 53.3\%$$

Similarly, timothy = 30.7%, redtop = 10.0%, red clover = 6.0%, total 100.0%

INCLINED POINT QUADRAT METHOD

This method is a modification of the method described above in which the needles pass to the ground at an angle of 45 degrees (Fig. 1B). A distinct advantage is gained if it is assumed that in a sward of clovers, grasses, and forbs the vertical needles would hit the larger leaved plants more frequently than the fine-leaved ones. From the observers standpoint the inclined needle is more clearly visible as it passes through the tall, thick vegetation than a vertical one, thus adding to the reliability of the data.

In our experience thus far, the point quadrat methods possess many merits as a rapid and reliable means of making botanical analyses of pastures in the Great Lakes region, and their usefulness will no doubt be shown in subsequent research in regions having a similar type of pasture sward. The inclined point quadrat method shows distinct advantages over the vertical by being more easily used; by covering a greater area per reading, thus recording a greater number of plants and consequently increasing the accuracy. If a botanical analysis is to be made in pasture research we suggest a point quadrat method be tried and perhaps the inclined point quadrat method will prove the more useful for most swards.

In continuing the present investigation emphasis will be placed largely on further development of the point quadrat methods and in testing the number of readings per acre necessary to obtain a reliable analysis of the pasture. Levy (6) has found in New Zealand that the dry weight of each species obtained from hand separations corresponds to the data obtained by the point quadrat method if analyzed as in D above. Henceforth, in the present study of methods, the herbage occupied by a representative area covered by both point quadrat methods will be clipped and the green and dry weight of each will be taken. The correlation between these results and the data obtained by using either point quadrat method will be determined.

SUMMARY

During the summer of 1936 six different methods for making botanical analyses of pastures, *viz.*, string, vertical and inclined point quadrat, specific frequency, percentage frequency, and percentage area, were tested for accuracy and practicability. Each method was applied in May and October at 30 randomized stations on two fields of 4½ acres each. The data were studied by Fisher's analysis of variance (Table 1). It was found that the methods, when used on pasture swards in the Great Lakes region, provided data differing markedly in type of information, accuracy, and labor involved. Also, some methods duplicated the information obtained by others.

On the basis of relative F values, labor, and accomplishment the use of the specific frequency and percentage frequency methods when used with a grid is not encouraged; and, if the information which either provides is desired, one of the two point quadrat methods or the string method may be used instead.

The two point quadrat methods show the greatest merits for a rapid and reliable means of determining the composition of a pasture, and in addition an indication of productivity. The inclined point quadrat method has the advantage of covering the greater area per reading and consequently increasing the accuracy, and of being more easily used in tall vegetation. More experience and data are necessary to evaluate accurately the respective merits of the methods and the purposes and conditions best adapted to their use.

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THE DETERMINATION OF SOIL REACTION UNDER FIELD CONDITIONS BY MEANS OF THE SPEAR-TYPE GLASS ELECTRODE[1]

W. T. McGeorge[2]

IN cropping the irrigated semi-arid soils of the southwest there are two phases of soil chemistry which require almost constant attention. One of these is the salt concentration of the soil solution (white alkali) and the other is the hydroxyl ion concentration (black alkali). The two conditions are closely related if the soluble salts are in large part sodium compounds. White alkali soils, in which the clay is largely saturated with sodium, will be changed to black alkali soils by leaching out the soluble salts. Such conditions influence soil productivity by seriously affecting the normal development of the plant as well as the soil structure.

A number of investigators have called attention to the effect of hydroxyl ions on the absorption of certain essential ions by roots.[3] The general opinion is that hydroxyl ions inhibit the absorption of negatively charged ions, notably phosphate and nitrate. In order to evaluate the reduced ion absorption it is necessary to know the pH of the soil under the growing conditions in the field. All methods now in use for the determination of pH in soils require too great a dilution of the soil with water. Since the hydroxyl ion concentration of alkali soils increases with dilution, the present methods yield only an arbitrary value which cannot be interpreted on a field basis. If the soil contains sufficient black alkali to be directly toxic, a pH determination at most any dilution will tell the story. In the border-line soils, that is those soils in which the hydroxyl ion concentration is not directly toxic but is sufficient to cause serious nutritional disturbances, there is need for greater precision.

The introduction of the spear-type glass electrode to methods of determining pH values prompted us to study its application to alkali soils as a means of determining the pH of the soil at field moisture contents. That is, the actual pH under which the plant must strive for a balanced nutrition.

METHOD

The method employed is extremely simple and requires little comment. Soils taken directly from the field, or air-dry soils to which varying amounts of water were added, were packed in small beakers and the glass and calomel electrodes were gently pressed into the moist soil. All the soils used were alkaline-calcareous soils which contain practically no organic matter.

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[1]Contribution from the Department of Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz. Received for publication July 20, 1937.

[2]Agricultural Chemist.

[3]Hoagland, D. R. The effect of hydrogen and hydroxyl-ion concentration on the growth of barley seedlings. Soil Science, 3:547. 1917.

McGeorge, W. T. Some aspects of citrus tree decline as revealed by soil and plant studies. Ariz. Agr. Exp. Sta. Tech. Bul. 60. 1936.

While a great many determinations have been made, only a limited number will be presented to illustrate the application of the method.

RESULTS

For the first experiment three soils, ranging in pH from 7.9 to 9.9 (1:5 dilution), were selected. To 100 grams of air-dry soil volumes of water varying from 10 cc to 1,000 cc were added. They were allowed to stand for 24 hours in order to reach equilibrium. For the soils to which the lowest amounts of water were added it was necessary to mix them well with a spatula in order to distribute the moisture thoroughly. The soils in the beakers were all packed by tapping the beakers on the table top and then the electrodes were gently pressed into the soil. The pH values obtained are given in Table 1.

TABLE 1.—*The effect of moisture content of soil on pH value.*

Vol water added per 100 grams soil	pH values of		
	Soil No. 1	Soil No. 2	Soil No. 3
10	7.45	9.10	7.95
15	7.55	9.15	8.05
20	7.65	9.35	8.00
25	7 60	9.40	8.00
30	7.50	9.40	8.00
40	7.60	9.60	7.90
50	7.65	9.65	7.95
100	7.70	9.85	8.20
500	7.90	9.90	8.95
1,000	8.15	9.90	9.20

These data show how the spear type of electrode can be used to determine the *p*H of semi-arid soils containing as little as 10% moisture. The data further show how the apparatus can be used to estimate the actual pH of the soil under any growing moisture conditions. The soils used in this experiment contained about 2% moisture when air dry and have a maximum water-holding capacity of 30 to 35%.

When an appreciable dilution of soil with water is required in a pH determination, the resulting value depends a great deal upon the character of the water used. In previous investigations[4] on the pH of alkaline-calcareous soils, we studied the values obtained with tap water, distilled water, and boiled distilled water. Using the dilutions required for the hydrogen electrode, boiled distilled water gives the highest pH value and tap water the lowest. On this basis it seemed of interest to determine if the character of water influenced the pH value when only 10 cc per 100 grams of soil were used. Such a test conducted on two soils is shown in Table 2.

There is a very close agreement in all the results obtained on the black alkali soil. When tap water was used on the slightly alkaline type, some reduction in pH was obtained after standing 24 and 48 hours, but the agreement at the 1-hour period was satisfactory. The

[4]McGEORGE, W. T. The measurement and significance of hydroxyl-ion concentration in alkaline-calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 57. 1935.

TABLE 2.—*Effect of tap water, distilled water, and boiled distilled water on pH value.*

Character of water used	pH values obtained after standing		
	1 hour	24 hours	48 hours
	Soil No 2		
Boiled distilled water	9.10	9.05	9.05
Distilled water . .	9.10	9.05	9.10
Tap water . .	9.10	9.00	9.05
	Soil No. 3		
Boiled distilled water	8.05	8.00	7.95
Distilled water . .	7.95	7.90	7.90
Tap water	8.05	7.85	7.80

results indicate that it makes very little difference which kind of water is used when only 10 cc per 100 grams of soil are used for the pH determination.

In Table 3 a group of analyses is presented to show the application of the method to soil samples just as they were taken from the field. These samples were taken from scattered areas around Tucson and include 1 black alkali soil and 12 alkaline-calcareous types. The soil samples were placed in tightly sealed cans in the field, brought to the laboratory where a portion of each was placed in beakers, packed by tapping on the table top, and the electrodes then gently pressed into the soil. The table also gives, for comparison, the pH of the soils after they had been dried and re-wet with 10 cc of water per 100 grams of soil and the pH values of the 1:10 soil water mixtures of both the fresh and air dry soils. The latter is the method now in use in

TABLE 3.—*The pH of the soil fresh from the field, after drying and re-wetting, and at 1:10 dilution.*

Soil No.*	pH values				
	Fresh†	Dried and re-wet‡	Fresh 1:10§	Dry 1:10§	Percentage water in field sample
4	7.70	7.75	8.05	—	18
5	7.75	7.85	7.95	—	19
6	7.60	7.60	9.10	9.00	16
6a	7.50	7.60	8.60	9.05	17
7	8.00	8.00	9.20	9.25	8
7a	8.00	7.95	9.20	9.25	11
8	7.75	7.80	9.15	9.20	8
9	7.75	7.65	8.95	9.15	10
9a	7.65	7.70	8 95	9.20	17
10	7.75	7.70	8.65	9.00	9
11	9.50	9.50	10.00	10.40	6
12	7.75	7.85	8.60	9.00	16
12a	7.95	8.05	8.95	9.20	15

*"a" represents subsoil, 2nd foot; all others first foot.
†Represents pH of fresh and air-dry soil in a mixture of 1 part soil and 10 parts boiled distilled water.
‡Represents soil after drying and re-wetting with 10 cc water per 100 gams of soil.
§Represents pH of soil at field moisture content.

this laboratory and yields a value which is considered the maximum potential alkalinity of the soil.

These data show that it is possible to determine the pH value of semi-arid soils at moisture contents as low as 6% and that it makes little or no difference if the soil is dried and re-wet for the determination.

SUMMARY

It is believed that the spear type of electrode has supplied a long-felt need to the soil specialist and agronomist. In it we have equipment and a method which yields a value that truly represents the pH of the soil under any and all growing conditions. In addition to this it opens up an unlimited field of application to nutritional and plant behavior studies which involve soil reaction in acid, neutral, and alkaline soils.

It has been in use in this laboratory for several months and the results may be obtained quickly and accurately and can be closely duplicated.

The electrodes are thoroughly cleansed with a stream of distilled water after each determination to remove adhering soil after which the electrodes are gently wiped with soft paper tissue. This leaves the electrodes slightly damp and assures immediate contact with the soil.

The Beckman type pH meter was used in these experiments because of the spear type of electrode and the extension cable which especially adapts it to this sort of work.

ANTHESIS OF MILLET, *SETARIA ITALICA* (L.) BEAUV.[1]

C. M. Heh, T. F. Mei, and S. S. Yang[2]

THE insufficiency of home-grown food stuff in China has directed attention to the improvement of important food crops. Millet is one of the chief food crops and is widely cultivated in north China, where it is grown both for the grain for human food and for the straw for fodder. Next to rice and wheat in importance, millet provides approximately 17% of the total amount of food consumed in China. Its breeding program has a history of over 10 years. Superior varieties of millet have been developed and multiplied and are now ready for distribution. However, the limitation in the use of pure-line breeding methods will result, sooner or later, in the application of artificial hybridization for further improvement.

The success of a cross depends largely upon the use of correct technic, which again, is developed through research on the flowering habits of the plant. This paper presents the results of two years' study on the anthesis of millet.

PREVIOUS INVESTIGATIONS

Rangaswami Ayyangar, *et al.*,[3] in India, upon the basis of six sets of observations on the flowering of millet, in three different years, reported that spikes begin to push out one week after the emergence of the flag. They also report that the opening of flowers commences between 8 p. m. and 10 a. m. when about three fourths of the head has emerged from the sheath, and proceeds from apex to base. Ten to 15 days are required for completion of the opening. Two peaks of flowering have been observed, one occurring between 10 and 12 midnight and the other between 6 and 8 a. m. The glumes of an individual flower may remain open for 1 hour in hot weather and 2 hours in cold weather. They found no noticeable effect on the characteristics of blooming due to varietal differences, but low temperature and high humidity were found to be favorable.

Li, *et al.*,[4] at Honan University, Honan, China, observed that millet blooming takes place 5 days after heading. A spikelet required 70 minutes on an average for the entire period from opening to closing. The most active period of daily blooming is at 5 a. m. and is followed by a rapid fall. Almost no flowers open between 10 a. m. and 3 p. m. Opening resumes gradually after 4 p. m. and is active again at 10 p. m. but with less intensity. Their observations, made with a single head in 1933 and three heads in 1934, disagree only slightly in the intensity of two flowering curves. The peak of the first curve was almost three times as high as that of the second in 1933, but both were about the same in 1934. They attribute this to the cooler temperature of 1933 and the higher temperature of 1934. The order of blooming regularly proceeds from apex to base. A spike may take 12

[1]Contribution from the Department of Agronomy, University of Nanking, Nanking, China. Received for publication August 3, 1937.

[2]Professor, Associate, and Assistant in Plant Breeding, respectively.

[3]Rangaswami Ayyangar, G. N., Narayanan, T. R., and Seshadri Sarma, P. Studies in *Setaria Italica* (Beauv.), the Italian millet. Part I. Anthesis and pollination. Indian Jour. Agr. Sci., 3:3. 1933.

[4]Li, H. W., Meng, C. J., and Liu, T. N. Problems in the breeding of millet, *Setaria Italica* (L.) Beauv. Jour. Amer. Soc. Agron., 27:963–970. 1935.

to 15 days to complete its flowering, depending upon the reaction to the environment and the variety used.

METHODS

A series of studies on the anthesis of millet was made both in the greenhouse and in the field at the University of Nanking in 1934 and continued in 1935. Altogether 15 days and nights (April 30 to May 14, 1934) were spent on investigations of the anthesis of 5,557 flowers from seven heads of the same strain in the greenhouse. The observations were repeated in the same year from August 28 to Sept. 8 in the field on 24,440 flowers from 13 heads of five different strains. In 1935, from May 23 to June 7, 7,961 flowers from 15 heads of three pure strains were again observed in the greenhouse. In the same year, from Aug. 14 to 25, 29,808 flowers from 15 heads of 14 pure strains were observed in the field. This study includes four sets of observations, two in the greenhouse and two in field, comprising 67,766 flowers from 50 heads of 18 representative varieties during a period of over 55 days and nights.

The spikes to be observed were grouped and numbered according to the dates when they were expected to flower. At an interval of 2 hours every day, records on the number of flowers opened, temperature, humidity, time required from heading to flowering, duration of blooming period of each flower, and order of flowering of each head were carefully taken. For the convenience of recognizing the opened flowers, all dehisced spikelets were removed with a fine-pointed forceps after the observations had been made.

RESULTS

PERIOD OF BLOOMING

The time required from the emergence of the head to the opening of the first flowers has been noted (Table 1). In the greenhouse, 30 heads were observed with an average period of 5.483 ± .098 days, and in the field with the same number of heads, 5.76 ± .18 days. The maximum blooming occurred on the fourth day. To complete the flowering of a head required from 8 to 16 days with an average of 12 days, depending upon weather conditions, whereas the size of the head seemed to have no influence. As the daily temperature and humidity in the greenhouse was less variable than in the field, the range of daily blooming obtained in the greenhouse did not show as wide irregularity as did that in the field (Fig. 1).

TIME OF DAILY FLOWERING

Daily flowering usually occurred between 8 p. m. and 10 a. m. with two periods of maximum blooming from 10 p. m. to 12 p. m. and 4 a. m. to 8 a. m. After these periods only a few flowers opened and activity had almost ceased at 2 p. m. The results are shown in Table 2.

From the four sets of observations it may be seen that the results in daily flowering obtained in the greenhouse did not agree with those obtained in the field. In the greenhouse the maximum flowering took place between 8 and 10 a. m. while in field it took place between 10 and 12 p. m. This may be attributed to differences in seasons and places but is likely due to variation in temperature and humidity which will be discussed later. By averaging all observations of flowering, 91% were recorded between 8 p. m. and 10 a. m. Of the two

TABLE 1.—*Percentage of flowers blooming each day in 1934 and 1935.*

Blooming day	1934 Greenhouse (April 30–May 14)	1934 Field (Aug. 28–Sept. 8)	1935 Greenhouse (May 23 June 7)	1935 Field (Aug. 14–Aug. 25)	Average
1st	3.64	0.71	3.96	1.80	2.53
2nd	14.72	6.52	6.23	11.16	9.66
3rd	18.12	15.65	6.39	21.04	15.30
4th	19.15	26.46	11.10	22.51	19.80
5th	15.96	19.46	13.18	14.31	15.73
6th	14.36	13 36	10.48	14.29	13.12
7th	9.43	5.57	8.04	5.16	7.09
8th	3.82	6.26	7.54	4.56	5.54
9th	0.68	4.05	6.64	2.52	3.47
10th	0.13	1 51	7.37	1.01	2.50
11th	—	0.27	8.19	1.01	2.37
12th	—	—	5.18	0.61	1.45
13th	—	—	3.08	—	0.77
14th	—	—	1.57	—	0.39
15th	—	—	0.82	—	0.20
16th	—	—	0.24	—	0.06
Total number of flowers	5,557	24,440	7,961	29,808	

peaks of blooming observed, the one between 10 and 12 p. m. included 20% of the total flowering and the other between 8 and 10 a. m. 17% of the total. As has been mentioned, although the first flowering peak has a higher intensity than the second when observed in field, the reverse is found to be true in the greenhouse; but the sum of flowering both in field and greenhouse between these two periods, i. e. from 8 to 12 p. m. and 6 to 10 a. m., give almost equal flowering percentages as shown by the following arithmetical additions: $11.77 + 19.78 = 31.55$; $14.67 + 16.97 = 31.64$.

ORDER OF FLOWERING

Order of flowering in a spike.—A spike emerges and elongates with its stalk about 5 days after the rising of the extended flag, but the increase in length will be confined to the stalk when flowering has taken place or 5 days after the emergence of the spike. As soon as all blooming is completed, the stalk ceases to elongate. Without exception, the flowering of a spike proceeds from the apex downwards.

Order of opening of a single flower.—A relatively long duration of blooming in a single flower has been observed. The average times required are from the beginning of glume spread to full open, 30 minutes; time during which the flower remains completely open, 30 minutes; and time from the beginning of closing to complete closing, 20 minutes. These phases of anthesis, giving a total time of 80 minutes, required for the completion of opening and closing in a single flower, are, however, influenced considerably by climatic conditions. As a rule, flowering is hastened by high temperature and low humidity.

TABLE 2.—*Average temperature, humidity, and blooming at 2-hour intervals in 1934 and 1935.*

Year	Place	Items	12–2 p.m.	2–4 p.m.	4–6 p.m.	6–8 p.m.	8–10 p.m.	10–12 p.m.	12–2 a.m.	2–4 a.m.	4–6 a.m.	6–8 a.m.	8–10 a.m.	10–12 a.m.
1934 (Apr. 30–May 14	Green-house	No. of flowers opened	5	22	26	311	632	851	210	625	610	1036	1204	25
		% of flowers opened	0.09	0.40	0.47	5.60	11.37	15.31	3.78	11.25	10.98	18.64	21.67	0.45
		Temperature, C°	32.1	29.9	24.8	21.0	19.6	19.1	17.7	17.3	17.1	21.6	26.3	29.3
		Relative humidity, %	61	65	74	79	86	90	92	95	95	87	76	69
1934 (Aug. 28–Sept. 8)	Field	No. of flowers opened	213	225	654	746	2903	5431	2951	1718	1901	4273	2640	785
		% of flowers opened	0.87	0.92	2.68	3.05	11.88	22.22	12.07	7.03	7.78	17.48	10.80	3.21
		Temperature C°	29.8	28.9	27.1	24.8	24.1	23.0	22.4	21.7	22.6	25.8	27.7	28.7
		Relative humidity, %	72	74	77	85	90	95	96	97	96	84	78	73
1935 (May 23–June 7)	Green-house	No. of flowers opened	60	40	41	67	95	983	1059	1084	653	596	2597	423
		% of flowers opened	0.78	0.52	0.53	0.87	1.23	12.77	13.76	14.08	8.48	7.74	33.74	5.49
		Temperature, C°	30.05	29.47	26.56	23.60	22.49	21.73	21.03	20.34	21.36	24.38	26.99	28.49
		Relative humidity, %	60	59	65	75	78	81	84	87	87	82	71	63
1935 (Aug. 14–Aug. 25)	Field	No. of flowers opened	235	96	860	1494	6616	8443	2969	979	2623	4345	493	130
		% of flowers opened	0.80	0.33	2.94	5.10	22.59	28.83	10.14	3.34	8.96	14.84	1.68	.44
		Temperature, C°	33.42	32.86	30.75	28.52	27.30	26.58	26.08	25.58	26.85	29.41	30.97	23.25
		Relative humidity, %	63	63	71	82	88	92	92	94	93	75	74	69
Mean of observations		No. of flowers opened	128.2	95.7	395.2	654.5	2561.0	3927.0	1797.2	1101.5	1446.7	2562.5	1733.5	340.7
		% of flowers opened	0.63	0.54	1.65	3.65	11.77	19.78	9.94	8.92	9.05	14.67	16.97	2.40
		Temperature, C°	31.34	30.28	27.30	24.48	23.37	22.60	21.80	21.23	21.98	25.30	27.99	29.68
		Relative humidity	64.00	65.25	71.75	80.25	85.50	89.50	91.00	93.25	92.75	82.00	74.75	68.50

The gradual spreading of glumes indicates the opening of the flower; and when they are fully spread, they sometimes give an angle of about 60 degrees. About the time the flower is fully opened, the plumose stigma first protrudes from the glumes. This is followed by the first anther 5 minutes later, and after 4 minutes, the other two anthers are pushed out at about the same time. Five minutes are

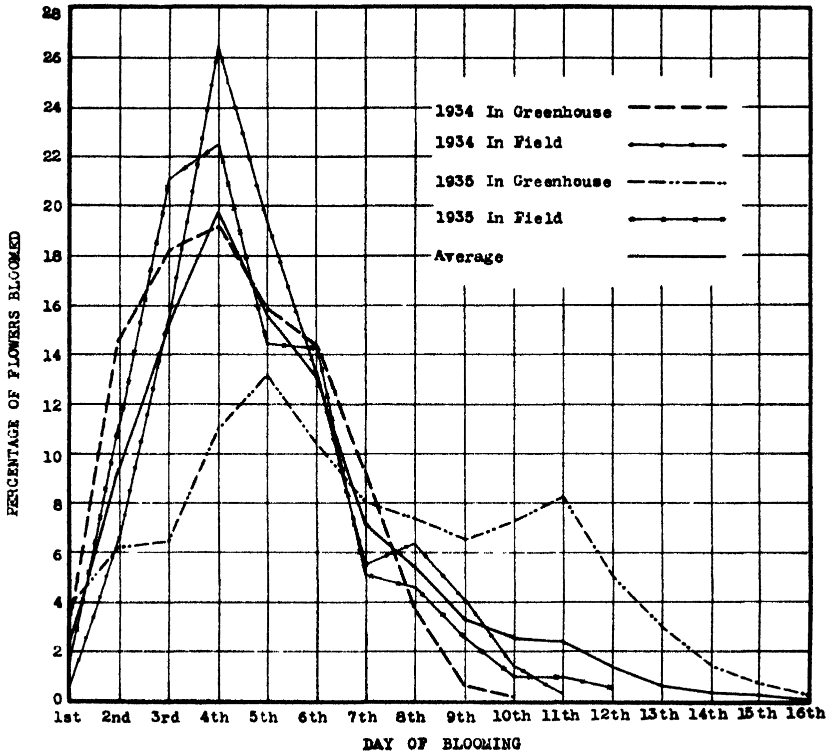

FIG. 1.—Distribution of the percentage of flowers blooming each day during the four observations made in 1934 and 1935.

needed for each anther to complete its emergence. The bursting of pollen sacs usually takes place within 2 minutes of the complete emergence of the anther. Ten or more minutes after the dehiscence of all anthers, the glumes commence to close, and after a period of 20 minutes complete closing has been reached. On a cloudy or rainy day, the closing activity may be delayed and continue for an hour or more. The stigma and anthers remain exserted after the glumes have completely closed and may persist for some time if they are not blown away by the wind or removed by other forces.

INFLUENCE OF TEMPERATURE AND HUMIDITY ON FLOWERING

As temperature and humidity are the two important modifying factors governing the periodicity of the anthesis of millet, records of temperature and humidity taken at the corresponding times of flowering are of interest in knowing the relationships between them.

From Table 2 it appears that, in general, the highest daily temperature occurs at 2 p. m. and the lowest at 4 a. m., while daily fluctuations in relative humidity are just the reverse, i. e., lowest at 2 p. m. and highest at 4 a. m. This is also shown in Fig. 2. As the flowering peak is confined to the period of low temperature and high humidity,

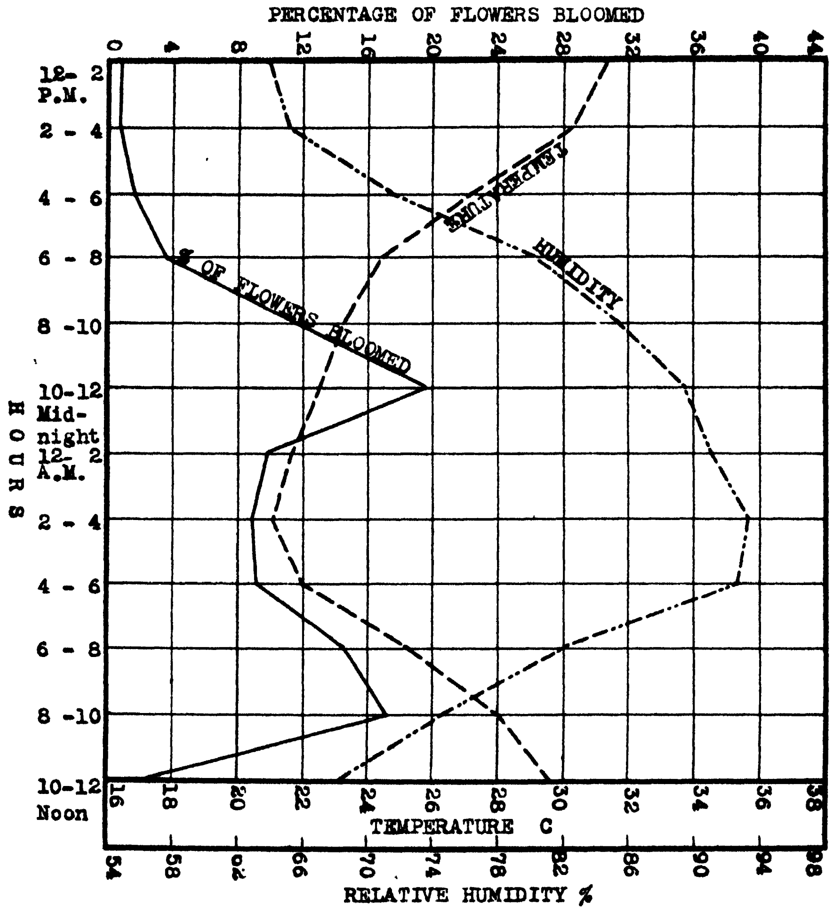

FIG. 2.—The average results of four observations on the average temperature, humidity, and flowering at 2-hour intervals during a single day.

indicating their direct effects, there seems, however, to be a great possibility of influence due to the fluctuation of temperature and humidity. The major portions of flowering do not take place at the time when temperature is lowest and humidity is highest (4 a. m.), but instead occur at 12 p. m. and 8 a. m. when rapid changes in temperature and humidity can be seen. It may be inferred that the fluctuation of temperature and humidity exerts great influence in the flowering of millet.

The diversity of weather conditions between the field and greenhouse resulted in the disagreement of observations on the time of an-

thesis. In the field the peak of flowering was reached from 10 to 12 p. m. and was revived again with lesser intensity the next morning; whereas in the greenhouse, the peak of flowering occurred from 8 to 10 a. m. with a second active period at midnight. This needs no comment and is entirely due to the making of observations at different places and seasons, which naturally vary in climatic conditions. It will be seen from Table 3 that both the average daily records of maximum and minimum temperature and humidity for the two years in the greenhouse taken during the months of May and June are lower than those in the field which were recorded in August and September.

TABLE 3.—*Minimum and maximum temperature humidity of different places during the time of observations in 1934 and 1935.*

Year	Place	Temperature C°		Relative humidity %	
		Min.	Max.	Min.	Max.
1934 (Apr. 30 May 14)	Greenhouse	17.1	32.1	61	95
1934 (Aug. 28–Sept. 8)	Field	21.7	29.8	72	97
1935 (May 23–June 7)	Greenhouse	20.3	30.0	59	87
1935 (Aug 14–Aug. 25)	Field	25.6	33.4	63	94

There is a tendency to bloom more actively in the morning and less actively at midnight if the temperature of the season is comparatively lower and the reverse condition is true if the temperature is higher. This also agrees with the results obtained in India and in Honan, China

Coefficients of correlation between number of flowers and temperature and humidity have been calculated,[5] and it is found (Table 4) that the number of flowers is negatively correlated with temperature and positively correlated with humidity.

TABLE 4.—*Coefficients of correlation between number of daily flowerings in per cent, and corresponding humidity and temperature.*

Year	Place of observation	r ± P. E.			R
		rTF‡	rHF‡	rTH‡	RTHF‡
1934	Greenhouse	−.456±.106	.553±.077*	.975±.005†	.668*
	Field	−.544±.089	.593±.079*	−.990±.002†	.667*
1935	Greenhouse	−.215±.153	.334±.130	−.955±.009†	.484
	Field	−.594±.079*	.580±.082*	−.986±.003†	.595

*Significant.
†Highly significant.
‡T = Temperature; H = Humidity; F = Percentage of flowers bloomed.

The humidity and temperature affected flowering collectively rather than individually. The simple correlation coefficients between temperature and flowering and between humidity and flowering are

[5]WALLACE, H. A., and SNEDECOR, G. W. Correlation and machine calculation Iowa State Col. Off. Pub., 30: No. 4:1–71. 1931.

much lower than the multiple correlation coefficients of the three variables. Instead of perfect correlation, the coefficients of multiple correlation vary between .48 and .67, which means that there must be other variables correlated with flowering. The undetermined variables may be soil moisture, light intensity, or others, but as no controlled experiment was made, no further conclusion can be drawn except to say that it is apparent that other factors besides temperature and humidity are involved in the environment of flowering.

FLOWERING HABITS AND HYBRIDIZATION OF MILLET

With the flowering of millet taking so much time, with the flowers remaining fully opened for about 30 minutes and requiring an hour more for the completion of blooming, and with the protruding of stigma from the glumes before the bursting of the anthers, the possibility of occasional natural crosses is apparent. From the results obtained in this study, it was found advisable to control pollination with paper bags on the third day of heading since blooming will commence on the fifth day. As a spike requires 8 to 16 days to accomplish blooming, the bag should be removed on the twentieth day, since the selfed heads will mold easily if enclosed in a warm moist bag and will also suffer from the blowing of the wind.

Artificial crossing may be made on the ninth day of its heading or the fourth day after the appearance of bloom where maximum flowerings are taking place. It is best to work in the morning before 10 a. m. First take off the bag and select for crossing the flowers that have begun to open, removing the remaining flowers. Care must be exercised to pull off all the undeveloped flowers, especially the spikelets at the basal part of the head which are still very tiny and not well developed when the majority of the flowers have fully opened. Failure to remove such florets completely, often allows them to develop and produce seeds which may be confused with the crossed spikelets.

Emasculation can be done when the first anther has just been pushed out and before the pollen sacs have burst. This is accomplished by clipping off the anthers with the aid of a pair of scissors and a fine needle. As an anther will take 6 or 7 minutes to complete its emergence, it allows calm work, but care should be taken not to break the pollen sacs and hurt the stigma. Pollination is accomplished by dusting the stigma with pollen grains of the dehisced anther of the foreign parent. The head is then rebagged for several days to prevent accidental contamination.

SUMMARY

In determining a correct technic for the crossing of millet, the study of the flowering habits of the plant is an absolute necessity. The writers have made four sets of observations in two different years, comprising 50 heads of 18 pure varieties.

The flowering of millet commences on the fifth day after the emergence of the spike, while the peak occurs on the ninth day. An average period of 12 days ranging from 8 to 16 days is required to complete flowering.

Daily blooming occurs from 8 p. m. to 10 a. m., but two maximum periods of flowering have been observed, one in which the first big rush is from 10 to 12 p. m. and a second period from 8 to 10 a. m.

The opening of flowers has practically stopped by 2 p. m. Flowering starts from the apex and progresses downward. A single flower may take about 80 minutes to accomplish the various phases of flowering and will remain completely open for 30 minutes. Weather conditions influence anthesis greatly, a relatively low temperature and high humidity favoring the process

THE NUMBERS OF AMMONIA-OXIDIZING ORGANISMS IN SOILS AS INFLUENCED BY SOIL MANAGEMENT PRACTICES[1]

R. H. WALKER, D. W. THORNE, AND P. E. BROWN[2]

THE factors affecting the nitrifying power of soils have been rather thoroughly investigated. The results of these studies have given but little information, however, concerning the abundance of the nitrifying bacteria under field conditions. The important function of these bacteria in the maintenance of soil fertility makes a determination of their presence of particular interest, yet in only a very few instances has any attempt been made to count the numbers of these organisms in the soil

The nitrate-forming bacteria have received more attention than those which transform ammonia to nitrite The work of some investigators (2, 12)[3] indicates that the ability to oxidize ammonia may be possessed by many widely different organisms of the soil. The present evidence, however, favors the assumption that the Nitrosomonas group of bacteria is the most important in this process In the present investigation a study has been made of the numbers of ammonia-oxidizing bacteria in soil as influenced by soil management practices

Wilson (11) was one of the first investigators to make counts of ammonia-oxidizing organisms of the soil. He found that the numbers varied widely from a few hundred to more than a million per gram. The number of organisms able to oxidize ammonia which were present decreased greatly as the acidity of the soils studied increased. It was also observed that the growth of leguminous crops seemed to favor larger numbers of these bacteria than non-legumes.

Feher (4) studied the nitrifying flora of forest soils. According to his results the pH of these soils exerted no noticeable effect upon the numbers of nitrifying bacteria. They were found in soils varying in reaction from pH 3.96 to 7.98. Some of the highest numbers were found in soils as acid as pH 4.51, while other soils with almost a neutral reaction were occasionally entirely lacking in these organisms. In general, the numbers of nitrifiers present closely paralleled the nitrate content of the soils. The numbers varied from 0 to 145,000 organisms per gram.

EXPERIMENTAL PROCEDURE

In this investigation some of the soil types common to Iowa were employed. Most of the studies were conducted on variously treated soils from the Agronomy farm of the Iowa Agricultural Experiment Station. Different systems of cropping and fertilizer treatments have been followed there on several series of plats for over 20 years.

[1]Journal paper No. J474 of the Iowa Agricultural Experiment Station, Ames, Iowa, Project No. 406. Received for publication August 3, 1937.

[2]Conservationist, Intermountain Forest and Range Experiment Station, U. S. Forest Service, Acting Research Assistant Professor of Soils, and Head of Department of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 863.

The samples taken from these plats consisted of a composite of 16 to 20 subsamples, systematically taken over the 1/10 acre plats. Only the surface 4 or 5 inches of soil were sampled. The studies were made by the modification of the dilution method as developed by Wilson (11). According to this method an ammonium sulfate nutrient solution was added to nitrite-free limestone in 250-cc Erlenmeyer flasks. The sterile medium in the flasks was inoculated in triplicate with 1-cc portions of various dilutions of the soil samples. After 3 weeks of incubation at 28° C, the medium of each flask was tested for the presence of nitrite by the alpha-naphthalamine-sulfanilic acid method. The greatest dilution of each sample showing the formation of nitrites was recorded. From these data the minimum numbers of ammonia-oxidizing bacteria per gram of soil were calculated.

For the greater part of these studies dilutions were made in stages of 10. In the counts made in the spring of 1937, those made on the different horizons of soils, and in the counts in the nitrification experiments, several intermediate dilutions were also made. Since the dilutions were rather wide, only comparatively great differences in numbers were noted. Consequently, the figures reported do not represent the exact numbers of these bacteria in the soils examined. Rather they represent an estimation of the minimum numbers. The true number for any given sample would be at some point greater than the highest dilution at which nitrite was formed and less than the least dilution at which nitrite was not formed. Since the intervening gap was in all cases rather wide the differences observed are undoubtedly of real significance.

RESULTS

GROWTH OF AMMONIA-OXIDIZING ORGANISMS DURING A NITRIFICATION EXPERIMENT

The numbers of ammonia-oxidizing organisms were determined at various periods during the course of a nitrification experiment. The soil employed was Grundy silt loam. This is the most extensively developed upland soil of southern Iowa. It is of loessial origin, dark brown to black in color, acid in reaction, and has a rather compact or impervious subsoil. The soil employed was secured from an experimental field in Clarke County. It had a lime requirement of about 3 tons per acre. The soil had been stored in a dry state for 2 years in the greenhouse before these tests were made. Various amounts of limestone were added on an acre basis (2,000,000 lbs. of soil per acre) to the portions of soil employed. The variously treated soils were placed in 100-gram portions in tumblers. To each was added 30 mgm of nitrogen as $(NH_4)_2SO_4$. The moisture was maintained at 50% of the moisture-holding capacity and incubation was at about 28° C. Duplicate cultures were conducted for each treatment. The numbers of ammonia-oxidizing organisms at the various intervals are shown in Table 1.

The results show trends similar to those obtained in the determination of nitrates at corresponding periods in the usual nitrification experiments. The necessity of a complete neutralization of acidity for the optimum activity of these organisms is well emphasized by data reported.

TABLE 3.—*The numbers of ammonia-oxidizing organisms at different times in the variously treated soils of the 2-year and 3-year rotation plats at the Agronomy Farm.**

Plat No.	Soil treatment†	1934				1936–1937		
		pH	Bacteria per gram of soil			pH	Bacteria per gram of soil	
			Apr. 19	May 22	Oct. 8		Oct. 15	Apr. 8
	2-year Rotation, Corn and Oats							
805	No treatment	6.00	1,000	10,000	100	6.00	100	5,000
806	M+L	6.87	100,000	1,000,000	1,000	7.37	1,000	10,000
807	M+L+RP	6.57	1,000,000	100,000	10,000	7.08	10,000	50,000
808	CR+L	6.94	1,000,000	10,000	10,000	7.01	1,000	25,000
	3-year Rotation, Corn, Oats, and Clover (Red Clover and Alfalfa Mixture)							
817	No treatment	6.00	10,000	10,000	1,000	5.63	100	5,000
818	M+L	7.37	100,000	1,000,000	10,000	7.19	1,000	10,000
819	M+L+RP	7.08	100,000	10,000,000	10,000	7.10	1,000	50,000
820	CR+L	7.01	10,000	1,000,000	1,000	6.74	1,000	10,000

*Oats were grown on all plats in 1934. Red clover and alfalfa did not grow on the 3-year rotation plats in 1934 because of the dry weather. Hubam clover was grown in 1935 as a substitute crop. Manure and rock phosphate applied to 2-year rotation plats Sept. 30, 1934 and Sept. 9, 1936. Manure and rock phosphate applied and red clover and alfalfa stubble plowed under in 3-year rotation plats Sept. 15, 1933, and Oct. 13, 1935.

†M = Manure, L = Lime, RP = Rock phosphate; CR = Crop residues.

TABLE 4.—*The numbers of ammonia-oxidizing organisms at different times in the variously treated soils of the 2- and 3-year rotation plats at the Agronomy Farm.**

Plat No.	Soil treatment	1934				1936–1937		
		pH	Bacteria per gram of soil			pH	Bacteria per gram of soil	
			May 1	June 14	Sept. 20		Oct. 7	May 14
	2-year Rotation, Corn and Oats							
811	No treatment	5.62	1,000	–1,000†	1,000	5.68	100	5,000
812	M+L	6.95	100,000	–1,000	10,000	6.74	10,000	25,000
813	M+L+RP	6.82	1,000,000	1,000	1,000	6.82	1,000	50,000
814	CR+L	6.94	1,000,000	–1,000	10,000	7.08	10,000	25,000
	3-year Rotation, Corn, Oats, and Clover (Red Clover and Alfalfa Mixture)							
829	No treatment	5.41	10,000	1,000	1,000	5.33	1,000	5,000
830	M+L	6.65	1,000	10,000	10,000	6.32	10,000	25,000
831	M+L+RP	6.82	10,000	10,000	100,000	6.80	10,000	75,000
832	CR+L	6.77	1,000,000	10,000	10,000	6.55	10,000	25,000

*Corn was grown on all plats in 1934. Manure and rock phosphate applied to 2-year rotation plats Aug. 24, 1933, and Oct. 14, 1935. Manure and rock phosphate applied and alfalfa and red clover stubble plowed under in 3-year rotation plats Aug. 22, 1933, and Oct. 7, 1936.

†–1000 = Less than 1,000 organisms per gram of soil.

studied. Although the plats reported in Table 4 received manure in the 2-year block and alfalfa and red clover residues and manure in the 3-year rotation block in the fall of 1933, no greater numbers of nitrifying bacteria were observed in the spring of 1934 than in the corresponding plats as shown in Table 3. The samples were not taken on the same days, however, so the results are not entirely comparable. The samples taken October 7, 1936, were secured about a month after manure applications to plats 830 and 831 and just before the red clover and alfalfa stubble was plowed under. Portions of undecomposed roots were present when the samples were taken May 14, 1937. No indication was obtained that these applications had greatly increased the numbers of nitrifying bacteria at the times of sampling.

There was a tendency for the highest numbers to be found in the spring months. The number of organisms as reported in Table 4 had greatly decreased by the time the samples were taken in June 1934. This can probably be best explained by the drouth and hot weather which were very severe that year. The somewhat lower counts obtained in the spring of 1937 are perhaps a result of the rather cold and wet weather prevailing at that time until nearly the middle of May. The data seem to indicate that the time of sampling was more important in relation to total numbers of ammonia-oxidizing bacteria than was the soil treatment. The relative trends in numbers with the different treatments were much the same, however, at the different times of sampling.

With the exception of the samples of May 1, 1934, there was a general tendency for the numbers of organisms to be greater in the 3-year than in the 2-year rotation plats as shown in Table 4. In the data reported in Table 3, however, there was no great difference in favor of either of the rotation systems.

The numbers of ammonia-oxidizing organisms were also determined in some of the 5-year rotation blocks. The rotation followed on these plats is corn, oats, red clover, winter wheat, and alfalfa. During the past 7 years it has been the practice to sow some alfalfa with the red clover. The alfalfa is allowed to remain on the land 5 years. The frequent production of legume crops supplies the soil with appreciable quantities of material having a high nitrogen content. Manure and rock phosphate are applied once in each rotation at the time the clover or alfalfa is plowed under the fall before corn is planted. The data obtained from a study of one block of plats in this rotation are shown in Table 5.

Manure and rock phosphate applications were made to this series of plats in the fall of 1932 and again about 6 weeks before samples were taken in October of 1936. The two sets of samples studied in the spring of 1934 were obtained during the time the land was being prepared for seeding oats and the legume crop.

The data show that the plat treated with manure and lime usually supported a greater flora of these organisms than the other variously treated plats. The manure, lime, and rock phosphate treated plat and the plat receiving crop residues, limestone, and rock phosphate also showed an increase in numbers over the untreated plats. Manure alone was not consistent in increasing the nitrifying flora of the soil

TABLE 5.—*The numbers of ammonia-oxidizing organisms at different times in the variously treated soils of the 5-year rotation plats at the Agronomy Farm.**

Plat No.	Soil treatment	pH		Bacteria per gram of soil				
		1934	1936	1933 Oct. 24	1934 March 20	1934 Apr 2	1936 Oct. 27	1937 May 17
1012	No treatment	5.72	5.60	10,000	100	10,000	1,000	10,000
1013	M	5.72	6.00	10,000	100	1,000	10,000	25.000
1014	M+L	6.85	6.73	100,000	10,000	10,000	10,000	25,000
1015	M+L+RP	6.87	7.00	10,000	1,000	1,000	10,000	25,000
1017	No treatment	5.84	5.80	10,000	100	100	1,000	10,000
1019	CR+L	6.77	6.58	10,000	100	1,000	10,000	25,000
1020	CR+L+RP	6.87	6.67	10,000	1,000	———	10,000	50,000

*Cropping system, 1933, corn; 1934, oats, red clover, and alfalfa; 1935, red clover and alfalfa; 1936, wheat and hubam clover. Manure and rock phosphate applied and clover plowed under Sept. 3, 1932, and Sept. 11, 1936.

in these tests. There is some evidence of a beneficial influence by treatments of crop residues and limestone upon these bacteria. As before, the most pronounced effects were secured where limestone was applied.

In Tables 6 and 7 data are reported which were secured in tests on other blocks of plats in the 5-year rotation series. Manure and rock phosphate applications were made to the 1024–31 series of plats in the fall of 1933, one year before the first samples were taken. The alfalfa and red clover stubble was plowed under in September of 1936, about

TABLE 6.—*The numbers of ammonia-oxidizing organisms at different times in the variously treated soils of the 5-year rotation plats at the Agronomy Farm.**

Plat No.	Soil treatment	pH		Bacteria per gram of soil		
		1934	1936	Nov. 9, 1934	Nov. 14, 1936	Apr. 13, 1937
1024	No treatment	6.22	6.14	1,000	1,000	1,000
1025	M	6.41	6.14	10,000	1,000	2,500
1026	M+L	7.48	7.28	100,000	1,000	50,000
1027	M+L+RP	7 74	7.50	100,000	1,000	50,000
1031	CR+L	8.11	7.97	10,000	1,000	25,000

*Cropping system, 1933, wheat and hubam clover; 1934, corn; 1935, oats and red clover and alfalfa; 1936, red clover and alfalfa. Manure and rock phosphate applied and clover plowed under Aug. 15, 1933. Red clover and alfalfa stubble plowed Sept. 4, 1936.

TABLE 7.—*The numbers of ammonia-oxidizing organisms at different times in the variously treated soils of the 5-year rotation plats at the Agronomy Farm.**

Plat No.	Soil treatment	pH		Bacteria per gram of soil		
		1934	1936	Nov. 14, 1934	Nov. 14, 1936	Apr. 13, 1937
924	No treatment	5.77	5.62	1,000	100	1,000
925	M	5.81	5.75	10,000	1,000	1,000
926	M+L	6.78	6.53	100,000	1,000	50,000
927	M+L+RP	6.82	6.76	100,000	1,000	50,000
931	CR+L	7.35	6.95	10,000	1,000	5,000

*Cropping system, 1930–34, alfalfa; 1935, corn; 1936, oats; 1937, Hubam clover (substitute crop). Manure and rock phosphate applied and alfalfa stubble plowed Sept. 4, 1934.

2 months before the samples were taken in that year. Alfalfa had been grown on the 900 series of plats for 5 years and until about 2 months before the first samples were taken. At the time of the first sampling of this series of plats numerous undecayed alfalfa roots were present in the soil. In 1936 the seeding of alfalfa and red clover failed due to drouth. Oats and hubam clover were seeded in the spring of 1937 as a substitute crop.

In both series there was a large increase in numbers of ammonia-oxidizing organisms in those plats which had received manure and lime and manure, lime, and rock phosphate. These increases were often 10 to 100 fold. The crop residues and lime and the manure alone treatments also gave increased numbers of these organisms at most samplings.

In the 1024–31 series no differences were noted in numbers of organisms in the variously treated plats in the fall of 1936. Furthermore, the number of nitrifiers, 1,000 per gram of soil, was comparatively small in comparison with the numbers observed at other periods of sampling. The results are hardly what would be expected in view of the fact that alfalfa and red clover stubble had been plowed under 2 months before the samples were taken. The fact that there was very little rain in October (0.84 inch), however, may be an important factor contributing to the low numbers. In the 900 series of plats, alfalfa had been plowed under about 2 months before sampling. In this case, however, comparatively large numbers of organisms were found. There were also great differences due to fertilizer treatments. Manure alone and crop residues and lime treatments induced 10-fold increases over the untreated soils; while the manure and lime, and the manure, lime, and rock phosphate treatments promoted a 100 fold greater growth.

In one block of plats corn has been grown continuously for more than 20 years. During this time the fertility of the soil in these plats has become so low that the yield and quality of the corn has greatly decreased. In this series the manure treatments were made once every 4 years. An application was made in the fall of 1931. The limestone applications have been made as needed. The numbers of organisms in these plats for the fall of 1934 are shown in Table 8.

TABLE 8.—*The numbers of ammonia-oxidizing organisms at different times in variously treated soils of the continuous corn plats at the Agronomy Farm.**

Plat No.	Soil treatment	pH 1934	Bacteria per gram of soil	
			Oct. 29, 1934	Nov. 27, 1934
906	No treatment	6.26	1,000	1,000
907	M	6.50	10,000	10,000
908	M+L	7.83	10,000	10,000
909	L	7.23	10,000	10,000
910	No treatment	6.39	1,000	1,000

*Manure applied October, 1931.

The data reported show that manure gave as great an increase in numbers of nitrifiers as did lime or manure and lime. The untreated

soils were somewhat lower in numbers than the treated. Although the numbers are not high, the results show that even soils greatly depleted by continuous cropping and which receive only very small additions of nitrogen-containing materials may possess an appreciable nitrifying flora.

DISCUSSION

The data obtained on the number of nitrifiers at different periods during a nitrification experiment show similar trends to the results secured by Dean and Walker (3) in their studies of the nitrifying powers of various acid Iowa soils. The necessity of complete neutralization of the soil for the maximum growth and activity of the nitrifying organisms is emphasized.

The numbers of ammonia-oxidizing organisms in various horizons of different soil types are in harmony with the general trends in bacterial numbers as reported by previous workers (10). Lipman (7) also found a decrease in the nitrifying powers of acid soils with depth.

Although the studies of nitrifiers in the soils of variously treated plats at the Agronomy farm were conducted for the most part during years of abnormal weather conditions, some definite relationships were brought out. Limestone applications induced a more consistent increase in numbers of organisms than any other soil treatment. This result is in agreement with the data secured by Wilson (11) in a similar study of the ammonia-oxidizing organisms in soils. In addition to limestone, a combination treatment of manure and rock phosphate supported greater numbers of these organisms in most cases than did manure or crop residues. In general, the plats receiving fertilizer treatments contained larger numbers of nitrifiers than those remaining untreated. These results were much the same on all blocks of plats regardless of the cropping system practiced.

It has been observed by other investigators (5, 10) that there is a good correlation between the fertility of soils and their nitrifying ability. This general relationship seems to apply to the variously treated soils of the different blocks of plats. There is no definite evidence, however, to show that any system of cropping induced larger numbers of nitrifiers in the soil than any other system.

Data secured in nitrification experiments (1, 5, 8) have shown differences in the nitrifying power of soils resulting from different cropping systems. In the cropping systems studied, which included the plowing under of legume residues in the soil in the 3- and 5-year rotations, it seems that there should be an increase in the nitrifying flora. A comparison of the results secured with soils of the 3- and 5-year rotation plats with those obtained on the 2-year rotation series, however, indicates that any such increase was only transitory, or was not great enough to be emphasized at the various periods of sampling with the technic employed. The method used in the present study, however, showed only the relative numbers of nitrite-forming organisms in the soil. Since nitrification tests measure the physiological efficiency of these groups of organisms, the results of the two methods of investigation would not necessarily be entirely in agreement.

Although samples were not taken consistently throughout the year,

the data secured do indicate that there was a much larger number of nitrifiers in the soil in the spring than at any other season. This is in agreement with the results of many investigations of nitrification throughout the various seasons of the year (6, 9). The workers cited attribute the maximum at this time chiefly to temperature and moisture relationships, but admit that other physical and chemical conditions may also contribute to the result.

SUMMARY AND CONCLUSIONS

1. The modification of the dilution method proposed by Wilson was employed for determining the approximate numbers of ammonia-oxidizing organisms in various soils. Most of the studies were confined to the variously treated plats of the Agronomy farm of the Iowa Agricultural Experiment Station.
2. The numbers of nitrite-forming bacteria developing during the course of a nitrification experiment varied with the amount and degree of fineness of the limestone applied to the soil employed.
3. The numbers of ammonia-oxidizing organisms in the profiles of several Iowa soils decreased rapidly with depth in passing from the A_1 to the A_2 and to the B horizons.
4. A study of the nitrite-forming flora of the variously treated Agronomy farm plats showed that large increases in numbers nearly always occurred where limestone had been applied.
5. In addition to the limestone applications, a combination treatment of manure and rock phosphate was probably the most favorable to these organisms. Manure or crop residues with limestone also usually brought about large increases in numbers over those found in untreated soils.
6. Manure alone favored an increased nitrifying flora in the plats cropped continuously to corn, but no such favorable effect was apparent in the 5-year rotation series.
7. No distinct differences in numbers were in evidence to show that any rotation studied was superior in favoring greater numbers of ammonia-oxidizing organisms than other rotations.
8. The nitrite-forming bacteria in the soils studied reached their maximum numbers in the spring months.
9. The data secured on the numbers of ammonia-oxidizing organisms in soils seem to be in general agreement with the conclusions of many previous reports on the nitrifying powers of soils.

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VARIATIONS OF THE HYDROCYANIC ACID CONTENT OF SUDAN GRASS FROM A SINGLE LOT OF SEED[1]

Charles F. Rogers, A. H. Larson, and Macy L. Spracher[2]

MANY champions of the use of Sudan grass for feed have insisted that sorghum in Sudan grass, taken either as pasture or as hay, explained the loss of animals that ate the feed. Others have suggested the presence of sorghum or of sorghum-Sudan grass hybrids. Crosses have been effected between a sorghum and Sudan grass in Australia (4)[3]. Such crosses are said to be easy to make and common when sorghum and Sudan grass flower near each other. Chemical analyses of the F_1 generation of such crosses and their parents indicate that the cyanide content of the hybrids may be much higher than that of either parent. In general, the cross sorghum × Sudan grass produces plants intermediate in size, appearance, and other characteristics. Moodie and Ramsey (4) claim that some of the hybrids they examined were higher in cyanogenetic glucosides than either parent, a condition which is genetically possible, but it seems improbable for many of the progeny of sorghum × Sudan grass crosses. No one has measured the individual variation of Sudan grass plants from the same planting with respect to seed used.

Swanson (7) has shown that hydrocyanic acid content of Sudan grass may at times be fairly high in young plants, but that it disappears as the plant matures. Sirrine (6) claims to have been able to select from samples of Sudan grass seed, individual seeds which would produce plants intermediate between sorghum and Sudan grass. All of the seeds she thought to be hybrids produced plants with intermediate characters, but many of the "normal," slender seeds also produced off-type plants, so that selection of hybrids on seed type alone would not separate all of the possible hybrids. If her ideas are correct, our information on Sudan grass seed types should be extended.

It is contended by Martin (3) that hybrids may be easily detected in the field by size and nature of the plant. Hybrids tend to approach the sorghums in vegetative type, in appearance of the inflorescence, and in seed characters.

The presence of harmful quantities of hydrocyanic (prussic) acid (HCN) has been generally assumed to be the cause of the poisoning of livestock by Sudan grass or sorghum. With sorghum, HCN has been occasionally *proved* to be the lethal agent. Many cases of death or illness from Sudan grass suggest the action of hydrocyanic acid because the deaths are sudden, and, where the animals are seen to die, death is violent or the animals collapse without a struggle and cease

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[3]Figures in parenthesis refer to "Literature Cited", p. 876.

to breathe almost "instantly." Recoveries, when they occur, are also usually rapid, as is the case in cyanide poisoning from plant sources.

Death by failure to breathe may be the result of the action of many poisons of which hydrocyanic acid is only one. Chemical detection of HCN in the stomach contents and especially *in the tissues* is essential for certain diagnosis of death by HCN.

In view of the prevalent idea of the potency of the hydrocyanic acid known to be in Sudan grass at times, of the reported powerfully cyanogenetic capacity of known hybrids, and of the deaths of cattle which had eaten of Sudan grass pronounced to be hybrids, it was deemed desirable to investigate the problem of types of plant from the standpoint of visible characteristics and of presence of HCN at various stages of development.

Larson, Rogers, and Spracher (2) have made a preliminary examination of the seeds which produced the plants used in this study. They failed to find significant differences between plants grown from one seed type compared to plants from another seed type, using seed shape and color as a criterion.

METHODS

A 5-acre upland tract was planted at University Farm in 1934 with seed labelled "pure Sudan grass" and free from sorghum as shown by examination of a large sample of the seed. After eight weeks of dry weather following planting, the plants were yet undeveloped. Late summer rains stimulated rapid growth during the first two weeks in September, when the field was inspected for plants which seemed to be off-type by virtue of heavier stems and wider leaves. In general appearance, those plants noted for their peculiarities which were chosen for measurement were distinctly different from the rest of the Sudan grass near them. The most certainly off-type plants were pulled up with closely associated plants, the earth shaken from them to find the seed, measurements made, and the plants potted while in the field for continued growth in the greenhouse during the winter.

When found the seed was preserved for classification. The leaves were measured for length and greatest width and uniform portions of the leaves taken for estimation of HCN by the Guignard (1) paper test which was scaled on the basis of 0 to 35, the possible detectible shades of difference. Readings were made after the test paper had been standing 24 hours in the presence of the leaves which had been artificially frozen and to which 2 ml of water had been added in the test tube.

RESULTS

The data in Table 1 are case histories of 79 individuals from the time they were taken from the field until immediately before the 29 surviving plants were planted outdoors. Plants Nos. 1, 6, 7, 10, 17, 18, 24, 25, 35–43, 47, 49–53, 62–67, 69–77, and 79 were much like sorghum when taken from the field on September 10 and 17, 1934. Of these Nos. 1, 30, 37, 40, 41, 47, 49, 64, 65, 71, and 77 continued to show sorghum-like appearance, but no regularity in HCN content. When planted in the field in July 1935, they grew vigorously and showed uniformly lower HCN content than in the greenhouse, falling to negative tests so consistently that no more tests for HCN were

taken. Even those most different from Sudan grass gave no more than traces of HCN after good growth started 10 days after transplanting. For this reason the last date of reading HCN is that in the greenhouse immediately before transplanting.

The apparent leaf breadth is the judged width referred to the length. Mature Sudan grass plants have much wider leaves than have young sorghum plants, but in general appearance mature Sudan grass leaves are narrower. For numerical convenience the length was referred to width to give ratios larger than unity, but these ratios are as truly a measurement of leaf shape as would be their reciprocals. Columns iii, vii, x, and xiii of Table 1 show these measurements, which are averages for all of the leaves on the plant, usually from five to eight. Wherever the plant was growing it was noticeable from the many measurements made that the length-width (l/w) ratio for successive leaves increased with rise up the stem to the leaf below the flag leaf. The flag leaf is both absolutely and relatively broader than the leaves below it on the stem. Total lengths of measured leaves were divided by total widths.

A constant 2-gram sample of fresh leaves was used for the HCN tests. These 2 grams were taken from at least five leaves, a section on one side was taken so that no leaf tissue would be left attached but cut off from its moisture supply. Slow growth in the greenhouse during the winter made impossible more frequent samplings than shown in Table 1. Five of the measured plants were not potted, 49 survived until the first measurement after transplanting in the greenhouse: 31 came through the winter and 29 were set out in low land on July 3, 1935. Changes in HCN, l/w ratios, and tiller counts with changes of soil and aerial conditions are clearly shown by the data under greenhouse reading. The column totals, averages, and standard deviations verify the more limited data of Larson, Rogers, and Spracher (2) in which it was shown that removal from the field to the greenhouse reduced the HCN content and narrowed the leaves of young plants.

When σ is of the same order of magnitude as the mean, significantly different means must be far apart. The standard deviations for the data of Table 1 are different from those given by Larson, Rogers, and Spracher (2) because there are more data here, but the same conditions exist. The variations are so great that significant differences between data taken on different dates of reading do not appear.

In order to discover what variations might exist between these two measured characteristics of Sudan grass, the scalings of HCN are collected in increasing order in column i of Table 2. The accumulated HCN scalings are used for each reading date in this table rather than the average because the total behavior of the plant is important. When more than one plant has the same total HCN scaling, the l/w sums are divided by the number of plants to represent that group of plants by a single number. Both frequencies and identification numbers of plants are given in adjacent columns.

The magnitude and sign of the correlation coefficients from these data will show whatever relation exists between the HCN of the plants and their tendency to resemble Sudan grass or depart therefrom. A high l/w value is taken to mean resemblance to Sudan grass.

TABLE 1.—*Size and color of seed of numbered plants, their HCN content on a scale of 0 to 35, average length/width (l/w) ratio for all of the leaves on the plants, and number of tillers for 79 plants taken from field L-3 September 10 and 17, 1934, and on three later readings in the greenhouse.*

Plant No.	From field L-3				In the greenhouse													
	Sept. 10 and 17, 1934				Nov. 8, 1934 *			Apr. 11, 1935			July 1, 1935			Total readings				
														Three		Four		
	Seed size and color	HCN	l/w ratio	No. tillers	HCN	l/w ratio	No. tillers	HCN	l/w ratio	No. tillers	HCN	l/w ratio	No. tillers	HCN	l/w ratio	HCN	l/w ratio
i	ii	iii	iv	v	vi	vii	viii	ix	x	xi	xii	xiii	xiv	xv	xvi	xvii	xviii
1	1, straw	1	15–	4	1	33–	2	3	23.0	many	0	20.0	6	5	71	5	91
2	1, straw	3	17.0	5	1	37	3	10	26.7	many	0	20.0	5	14	81	14	101
3	No seed	1	16.3	4*													
4	2, straw	2	22.2	5	3	15.8	10	9	24.5	many	0	17.1	10	14	63	14	80
5	2, black	4	15.9	3*													
6	1, brown	3	14.3	0	†												
7	2, brown	3	16.5	9	3	55.0	14	9	23.3	many	0	25.4	many	15	95	15	120
8	2, black	3	23.6	2*													
9	2, brown	8	15.5	3	6	32.6	1	9	17.1	many	0	20.0	many	23	65	23	85
10	2, black	6	11.7	4	†												
11	1, brown	1	21.8	1*													
12	No seed	3	17.7	5	5	32–	8	3	17.9	many	†			11	68		
13	1, straw	5	23.0	5	1	30.0	2	8	24.6	many	0	20.0	2	14	77	14	97
14	No seed	12	15.6	3	6	13.0	0	10	27.3	many	7	17.1	many	28	56	35	73
15	2, brown	3	15.6	6	4	22–	0	0	17.5	6	0	23.9	many	7	55	7	79
16	–	4	17.9	2	6	16–	0	†									
17	2, brown	3	13.4	2	3	33.3	0	8	26.6	1	0	15.0	1	14	73	14	88
18	No seed	8	9.7	1	†												
19	No seed	3	14.3	0*													

20	2, brown	2	20.0	4	2	20.0	2	0	30.0	8	0	22.2	many	4	70	4	92
21	1, brown	1	24.4	6	1	50.0	1										
22	2, black	3	14.5	4	3	17–	0	2	21.0	2	0	13.1	0	8	53	8	66
23	No seed	12	10.5	0													
24	No seed	14	8.9	0													
25	No seed	13	9.4	0													
26	2, brown	15	11.6	3													
27	1, straw	10	15.7	4	3	20.0	0	4	27.1	0	0	20.0		17	63	17	83
28	–	4	30.0	2													
29	No seed	20	10.0	0													
30	2, brown	5	12.0	2	3	10.5	0	0	20.8	0	0	17.1	0	8	43	8	60
31	No seed	4	18.3	5													
32	2, brown	4	24.7	4	6	23-	0	0	20.0	4	trace	17.5	many	10	68	10	84
33	2, black	2	15.6	5													
34	1, brown	1	13.2	0	9	30	0										
35	1, brown	3	13.3	0	9	30											
36	1, brown	4	15.0	8	1	37.4	5	1	24.4	many	0	28.8	many	6	77	6	103
37	No seed	6	12.9	3	1	20.4	4	0	25.4	0	0	19.3	many	7	59	7	78
38	2, brown	10	15.3	1													
39	1, brown	3	14.3	4	4	33	4	6	24.7		0	13.6	many	13	72	13	86
40	1, black	5	15.6	5	4	15.0	sprouts										
41	2, black	4	15.5	3	2	11.5	2	0	31.1	3	0	22.7	4	6	58	6	81
42	2, brown	3	16.9	4	10	15.3	0										
43	1, straw	7	15.4	5													
44	1, brown	14	16.2	4	4	24-	1	6	23.9	many	0	18.4	0	24	64	24	82
45	1, brown	4	19.0	7	1	18.6	3										
46	1, brown	3	15.0	3	2	19.5	1										
47	1, straw	2	13.6	3	2	16.1	2	0	21.7	many	0	21.11	11	4	51	4	73
48	1, straw	3	15.0	7													
49	3, black	4	10.7	1	6	14.6	1	5	17.8	2	3	10.9	0	15	43	18	54

*Plants not potted

†Plant died before this date of observation. All vacant spaces after or below indicate death of plants after the last reading shown

TABLE 1.—*Concluded.*

Plant No.	From field L-3, Sept 10 and 17, 1934: Seed size and color	HCN	l w ratio	No tillers	In the greenhouse, Nov 8, 1934: HCN	l w ratio	No. tillers	Apr. 11, 1935: HCN	l w ratio	No. tillers	July 1, 1935: HCN	l, w ratio	No. tillers	Total readings, Three: HCN	l, w ratio	Four: HCN	l/w ratio
i	ii	iii	iv	v	vi	vii	viii	ix	x	xi	xii	xiii	xiv	xv	xvi	xvii	xviii
50	1, brown	18	11.4	3													
51	1, straw	8	12.9	0	6	16.5	0										
52	2, brown	5	13.2	0	6	30.0	0	5	17.8	0				16	61		
53	2, brown	4	12.1	2	1	11.8	0										
54	1, straw	5	16.7	5	3	14.7	2	8	25.7	many	5	22.8	13	16	57	21	80
55	1, straw	6	14.7	8													
56	1, straw	6	20.0	8	4	31.3	4	8	32.2		4	22.1	many	18	84	22	106
57	No seed	1	15.6	8													
58	1, straw	2	14.1	3	7	21.9	0										
59	1, straw	10	18.0	6													
60	1, brown	4	15.0	1	2	18.2	0	0	22.4	6	0	20.6	5	6	56	6	76
61	1, straw	8	19.3	5	1	46.9	0										
62	1, straw	8	12.8	4	7	28.9	1										
63	1, brown	4	13.0	5													
64	No seed	9	12.9	4	2	33.2	4	6	31.4	many	2	25.0	many	17	78	19	103
65	No seed	16	8.9	0	2	10.6	0	8	10.7		6	16.9	0	26	30	32	47
66	No seed	14	10.0	0													
67	1, straw	15	15.7	4													
68	1, straw	6	18.5	3													
69	2, black	15	14.6	4													

70	1, brown	12	12.9	4	2	36.3	3										
71	2, brown	7	10.9	1	1	26.0	1	0	23.3	many	0	19.3	15	8	60	8	80
72	2, brown	20	14.7	1	4	25.5	0										
73	2, brown	15	11.1	0													
74	1, brown	12	11.3	0													
75	No seed	20	12.2	0													
76	No seed	35	8.8	0													
77	2, brown	35	15.6	5	10	37.4	6	5	22.7	many	2	16.7	many	50	76	52	92
78	1, brown	8	20.0	4	2	43.9	2	0	32.2		1	28.5	6	10	96	11	125
79	1, straw	18	13.6	4													
Totals . .		614	1,200.0	253	172	1,178.7	89	133	734.8	‡	30	572.1	‡	434	2,023	437	2,465
No. plants involved			79			46			31			29		31		29	
Averages .		7.8	15.2	3	4	25.1	2	4	23.7		1	19.7		14	65	15	85
Standard deviations		±6.88	±3.95	±2.35	±2.55	±10.50	+2.8	±3.65 ±4.16			±1.97	±3.94		±8.97	±14.19	±10.5	±17.0

*Plants not potted
†Plant died before this date of observation. All vacant spaces after or below indicate death of plants after the last reading shown.
‡Where tillers became numerous and small, counting might damage them, this condition was indicated by "many". An average of these values is therefore impossible

TABLE 2.—*HCN scaling totals, frequencies, and average l/w ratios of two, three, and four readings of surviving plants on the dates shown.*

Total HCN scalings	Nov. 8, 1934 (2 readings)			April 11, 1935 (3 readings)			July 1, 1935 (4 readings)		
	Frequencies	Average l/w	Plant Nos.	Frequencies	Average l/w	Plant Nos.	Frequencies	Average l/w	Plant Nos.
i	ii	iii	iv	v	vi	vii	viii	ix	x
2	2	61	1, 21						
4	3	41	2, 20, 47	2	61	20, 47	2	83	20, 47
5	5	37	4, 36, 45, 46, 53	1	71	1	1	91	1
6	6	44	7, 13, 17, 22, 41, 60	3	64	36, 41, 60	3	86	36, 41, 60
7	3	39	15, 37, 39	2	57	15, 37	2	79	15, 37
8	4	35	12, 30, 54, 71	3	52	22, 30, 71	3	69	22, 30, 71
9	3	44	40, 58, 61						
10	6	44	16, 32, 34, 49, 56, 78	2	82	32, 78	1	85	32
11	2	45	52, 64	1	68	12	1	125	78
12	1	43	35						
13	2	34	27, 42	1	72	39	1	86	39
14	3	42	9, 51, 70	4	74	2, 4, 13, 17	4	94	2, 4, 13, 17
15	1	42	62	2	69	7, 49	1	120	7
16				2	59	52, 54			
17				2	70	27, 64	1	83	27
18	3	29	14, 44, 65	1	84	56	1	54	49
19							1	103	64
21							1	80	54
22							1	106	56
23				1	65	9	1	85	9
24	1	49	72	1	64	44	1	83	44
26				1	30	65			
28				1	56	14			
32							1	47	65
35							1	73	14
45	1	53	77						
50				1	76	77			
52							1	92	77

Ordinarily, the l/w for sorghum is not more than 8 to 14 in young plants. The Harris formula was used for calculations of r:

$$r_{xy} = \frac{\frac{\Sigma (xy)}{N} - \bar{x}\bar{y}}{\sigma_x \cdot \sigma_y}$$

Let x always be the values of column i of Table 2, with the frequencies shown in columns ii, v, and viii, then xy will be products of columns i by ii by iii, or i by v by vi, or i by viii by ix, and Σ (xy) will be the sum of such products for any one reading date.

Identifications and data taken from the previous tables are shown in Table 3.

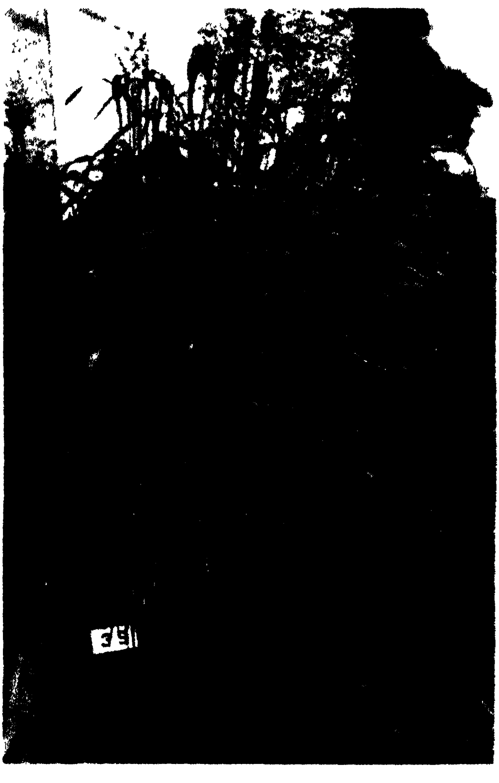

FIG 1.—Plant 39 Seed "1, brown" always Sudan grass-like in the greenhouse and field.

Although the first correlation coefficient has the proper sign and might be considered to have some significance, it is well to remember that only about 24% of the variation $(r_{xy})^2$ is thus shown to be in any sense a covariance. As this covariance is not maintained in later tests (shown by the almost invisible values of the later computed r_{xy}'s), one might conclude that cyanide content and the most obvious distinguishing appearance of the plants called Sudan grass cannot always be taken as an indication of their potential HCN content. The conditions during the summer of 1934 reduced growth because of lack of moisture, and the HCN level was higher. In the greenhouse light intensity was probably the limiting factor and HCN decreased, but when abundant moisture, space, and light permitted great growth as shown in the figures, the HCN content of these plants which differed widely in other characteristics became essentially the same in their negative tests for HCN. There seems to be no choice among them as to danger of prussic acid poisoning in the later stages when truly different leaf proportions and size and number of stems from one crown are certainly evident.

Plants Nos. 1, 2, 4, 7, 9, 12, 13–15, 17, 20, 22, 27, 30, 32, 36, 37, 39,

TABLE 3.—*Standard deviations and correlation coefficients for HCN scalings with l/w averages for HCN classes.*

Reading dates	Column No.	N	Standard deviations	Correlation coefficients
		Table 1		
Sept. 10 and 17, 1934	iii	79	6.88 HCN	iii with iv .4912
	iv	79	3.95 l/w	
		Table 2		
Nov. 8, 1934	i and ii	46	6.94 HCN	HCN with l/w 0.00133
	ii and iii	46	6.50 l/w	
Apr. 11, 1935	i and v	31	9.13 HCN	HCN with l/w .057
	v and vi	31	10.78 l/w	
July 3, 1935	i and viii	29	10.55 HCN	HCN with l/w .0736
	viii and ix	29	16.00 l/w	

FIG. 2.—Plant 30. Seed "2, brown" low in HCN, but about the most sorghum-like of all plants saved.

41, 44, 47, 49, 54, 56, 60, 64, 65, 71, and 77 were planted on July 3, 1935, in low land where moisture was abundant. All but Nos. 22 and 27 lived. The soil was so level and apparently so uniform that soil differences could not account for the vast differences in types of plants which developed. Most of the plants had Sudan grass-like inflorescences, some on fine bush plants such as No. 39 shown in Fig. 1, others on stemy plants like No. 30 (Fig. 2) with its few tillers, and yet others intermediate in form between these extremes as shown in plants Nos. 7 and 17 (Fig. 3).

If other sets of plants from equally uniform seed should produce in the field plants of as widely different characters but with as little ultimate variation in HCN in the plants, it will be necessary to conclude, as have Rogers and Boyd (5) from other considerations, that, although Sudan grass may have intoxicative action on animals, much of that action must be ascribed to some other kind of intoxication than HCN.

CONCLUSIONS

For lack of detail, existing descriptions or measurements of Sudan grass seeds do not make possible a study of their variations to anything like the degree of accuracy which is now possible with the plants from which they came, or which come from the seeds. Larson, Rogers,

FIG. 3.—*Left*, plant 7, seed "2, brown," *right*, plant 17, seed "2, brown." Plants are much alike in cyanide content and appearance. Intermediate between Nos. 39 and 30.

and Spracher (2) could not show significant differences between Sudan grass plants from apparently different seeds either in l w ratio of the leaves or in the HCN content of the plants. This may be as much because the seeds were not closely enough classified as because of apparently insignificant variation. One cannot correlate variants unless there are about the same number of classes with about the same relative range of significant differences between the classes of the two variants. Limits of variation of measurable traits of Sudan grass plants should be ascertained under conditions which can be exactly standardized and reproduced.

Then, too, unless the HCN content of Sudan grass is shown to be more closely associated with true cyanide poisoning of animals known to be ill or dead from eating Sudan grass than some now believe it to be, or unless the desirable qualities of Sudan grass are shown to be related to cyanogenetic activity, which is probably the case, the im-

mediate practical justification of further study may not be great. On the other hand, if conditions highly favorable to cyanogenesis should show some significant correlation with plant type and HCN content of plants, and if these plants could be used to cause cyanide deaths in animals, pursuit of this problem would be practically as well as scientifically justifiable.

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A COMPARISON OF THE NUMBERS OF TWO SPECIES OF RHIZOBIUM AND AMMONIA-OXIDIZING ORGANISMS IN VARIOUSLY TREATED IOWA SOILS[1]

D. W. THORNE AND P. E. BROWN[2]

THE nodule bacteria of leguminous plants and the nitrifying organisms are very important in the nitrogen cycle and the maintenance of soil fertility. The results of many investigations (2)[3] have shown that the nitrifying power of a soil is frequently closely related to its fertility. More recent studies (1, 3, 4, 5) have also shown that the numbers of root-nodule bacteria in soils vary greatly with fertility and especially with fertilization and cropping history.

EXPERIMENTAL

At various periods during the past 4 years simultaneous determinations have been made of the numbers of alfalfa and red clover nodule bacteria and ammonia-oxidizing organisms in certain Iowa soils. This work has been largely carried out on the soils of the variously treated and cropped plats on the Agronomy farm of the Iowa Agricultural Experiment Station. The data obtained have been partially published (5, 6) as separate studies of the Rhizobium and ammonia-oxidizing organisms in the soil. The purpose of the present paper is to point out some of the relationships between the occurrence of these two groups of organisms.

The soil samples studied were obtained from several series of plats which have been subjected to various fertilizer treatments and crop rotations for more than 20 years. Plats from three different rotations have been included in this investigation. These include a 2-year rotation of corn and oats; a 3-year rotation of corn, oats, and red clover; and a 5-year rotation of corn, oats, red clover, winter wheat, and alfalfa. During the past 7 years it has been the practice to sow some alfalfa with the red clover. The alfalfa of the 5-year rotation is allowed to remain on the land 5 years. The soils of the 2-year rotation plats are at present much lower in fertility than those under the other rotations. The soils of the 5-year rotation have a higher fertility than those of the 3-year rotation. This is undoubtedly due to the fact that the 5-year rotation plats were originally located on the most fertile area of the field. The 3-year rotation is usually considered the best for a soil-building program.

For most of the determinations of numbers of organisms, dilutions were made in stages of 10. In the counts made in the spring of 1937 several intermediate dilutions were also included. Since the dilutions studied were for the greater part at logarithmic stages, the distribution of the organisms can probably be shown to the best advantage on a logarithmic scale. In Figs. 1, 2, and 3 dot diagrams are shown of

[1]Journal paper No. J477 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 406. Received for publication August 7, 1937

[2]Acting Research Assistant Professor of Soils and Head of Department of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 882.

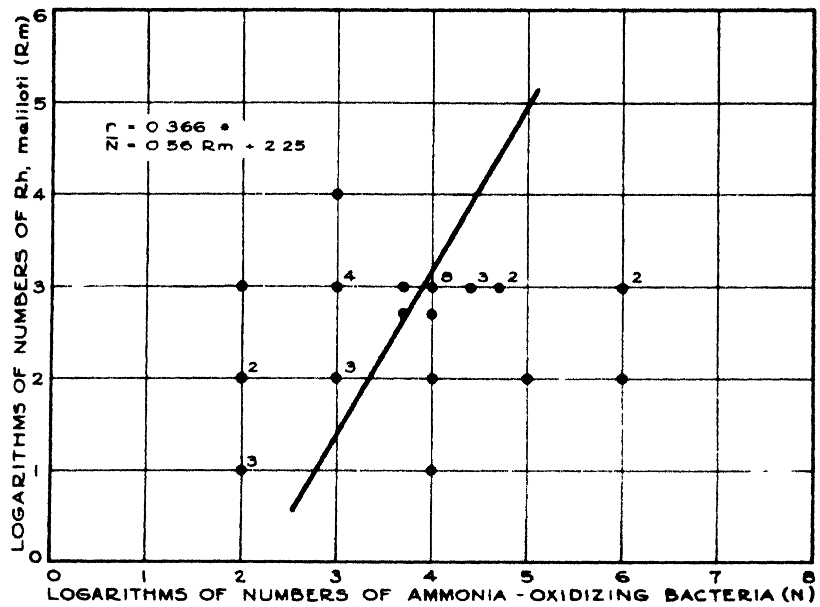

FIG. 1.—Logarithms of numbers of *Rh. meliloti* and ammonia-oxidizing organisms in soils of the variously treated 2-year rotation plats

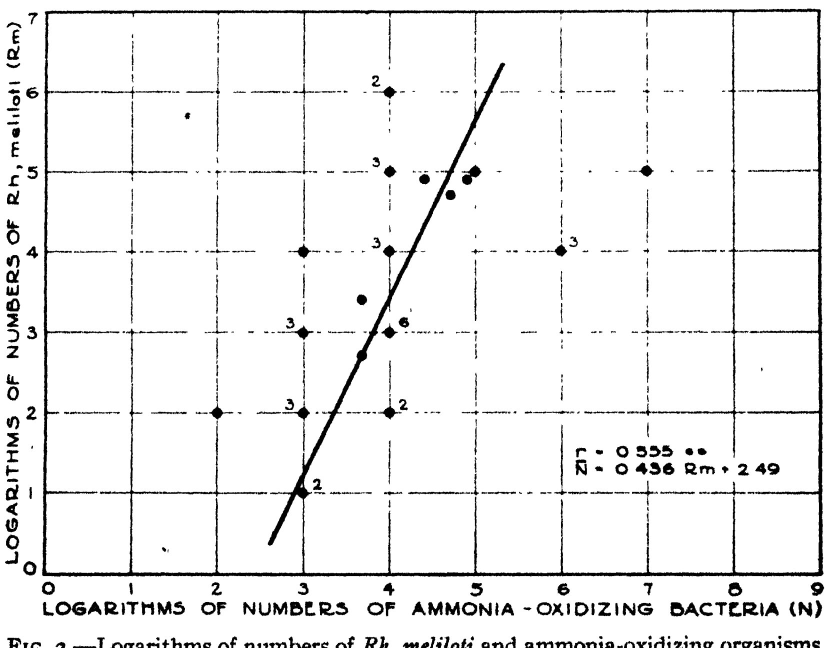

FIG. 2.—Logarithms of numbers of *Rh. meliloti* and ammonia-oxidizing organisms in soils of the variously treated 3-year rotation plats.

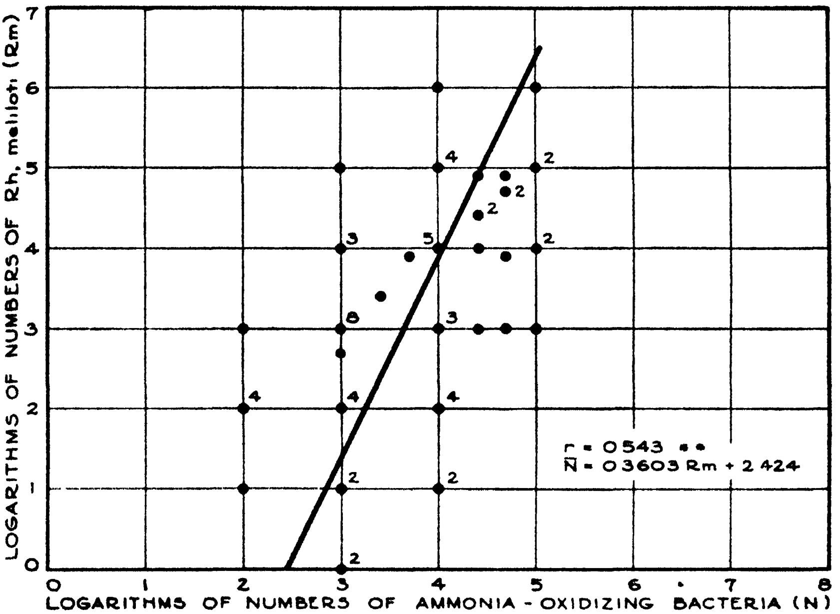

FIG. 3.—Logarithms of numbers of *Rh. meliloti* and ammonia-oxidizing organisms in soils of the variously treated 5-year rotation plats.

the logarithms of numbers of *Rh. meliloti* and ammonia-oxidizing organisms in soils of the variously treated plats of the 2-, 3-, and 5-year rotation series, respectively

The correlation between the numbers of *Rh meliloti* and *Rh. trifolii* was highly significant in all instances For this reason approximately the same relationships between bacteria of these species and the ammonia-oxidizing organisms may be assumed. A comparison of the distribution of dots in the three figures shows that similar distributions of organisms were found in the soils of the 3- and 5-year rotation plats. The numbers appear much less closely related in soils of the 2-year rotation plats. These observations are substantiated by the correlation coefficients calculated from the logarithms of numbers. For the 5-year rotation r = 0.543, for the 3-year plats r = 0.555, while for the 2-year plats r = 0.366. These values are highly significant in the first two instances, but just significant in the last case. Since 65 sets of values were included in the calculation of the coefficient for the 5-year rotation but only 36 values in the 2- and 3-year plats, the numerical values of the correlation coefficients are not directly comparable.

The correlation coefficients were also calculated employing the actual numbers of organisms. Since the logarithmic spacing of the dilutions gave only rather wide differences in numbers, it is very difficult to establish such a correlation. Especially is this true in cases where a few numbers of 1,000,000 were found, while most of the values ranged from 100 to 10,000 or even 100,000. Nevertheless, the correlations ob-

tained, while not usually significant, show similar trends to those observed in the coefficients calculated from the logarithms of numbers (for the 5-year plats $r = 0.258$, for the 3-year $r = 0.00265$, for the 2-year $r = 0.00143$. The value for the 5-year rotation is significant. The other two coefficients are not significant.)

The regression equations given for the three series show that the nitrifying organisms did not approach as small a minimum as the legume bacteria. According to these equations, as the number of *Rh. meliloti* approached zero, the number of nitrite-forming organisms approached 180 in the 2-year rotation, 27 in the 5-year plats, and 310 in the 3-year plats.

The differences in the relationships between the organisms in soils cropped to the different rotations are probably due to the fact that the 3- and 5-year rotations include frequent crops of the host plants of the legume bacteria studied. This has probably been an important factor in maintaining a flora of these organisms in the soil. The legume residues also furnish nitrifiable material for the ammonia-oxidizing organisms; consequently, rotations containing legumes might also be expected to promote a more suitable environment for the nitrifying bacteria. The numbers of nitrifying organisms were not greatly affected, however, by the rotations studied (6).

Since the numbers of organisms fluctuated considerably at different seasons of the year, the influence of soil treatment upon numbers can only be compared during restricted periods. More determinations of numbers were made in October and the first part of November than at any other similar period. Accordingly, the numbers of organisms found in the similarly treated soils for each rotation during these months were averaged. These data are given in Tables 1 and 2. The average results of three determinations are given for the 2- and 3-year rotation plats, while the averages of six determinations are given in the 5-year plats.

TABLE 1. —*Average numbers of bacteria per gram of soil in the 2- and 3-year rotation plats in October of 1934 and 1936 (three determinations).*

Soil treatment	*Rh. meliloti*	*Rh. trifolii*	NH_3-oxidizing bacteria
2-year Rotation, Corn and Oats			
No treatment	40	40	100
M+L	700	700	4,000
M+L+RP	1,000	1,000	7,000
CR+L	700	700	7,000
3-year Rotation, Corn, Oats, and Clover (Red Clover and Alfalfa Mixture)			
No treatment	40	40	700
M+L	336,700	36,700	7,000
M+L+RP	34,000	4,000	7,000
CR+L	333,000	33,700	7,000

These data show that the organisms of both groups were greatly influenced by fertilizing treatments. The variations of the different organisms with soil treatments have been stressed previously (5, 6).

TABLE 2.—*Average numbers of bacteria per gram of soil in the 5-year rotation plats in October of 1934 and 1936 (six determinations).*

Soil treatment	*Rh. meliloti*	*Rh. trifolii*	NH_3-oxidizing bacteria
No treatment	218	533	2,350
M	1,735	3,683	7,000
M+L	20,335	5,333	52,000
M+L+RP	203,333	23,333	37,000
CR+L	20,350	3,683	7,000

A comparison of the numbers of each of the organisms studied, however, shows that greater fluctuations were found in the numbers of legume bacteria than in the nitrifying organisms. All three groups showed a definite response to fertilizer treatments Although there are a few figures in these tables of averages which are not entirely in agreement with the general conclusions of the previous papers, the various organisms showed a similar response to the different soil treatments

One other point may be brought out which is not shown by the data given in this paper Maximum numbers of ammonia-oxidizing organisms were found in the spring or early summer. The legume bacteria did not show any distinct seasonal fluctuations in numbers, although they are undoubtedly affected by soil temperature and moisture relationships.

SUMMARY AND CONCLUSIONS

1. The approximate numbers of *Rh. meliloti*, *Rh. trifolii*, and ammonia-oxidizing organisms in variously treated soils on the Agronomy farm of the Iowa Agricultural Experiment Station were determined at several different periods.

2. The logarithms of the numbers of *Rh. meliloti* and *Rh. trifolii* in the soils studied had a highly significant correlation

3. The logarithms of numbers of *Rh meliloti* and nitrite-forming organisms in the variously treated soils cropped to the 3-year rotation of corn, oats, and clover were highly significantly correlated. In similarly treated soils cropped to a 5-year rotation of corn, oats, red clover, winter wheat, and alfalfa, a highly significant correlation between these organisms was also noted. The correlation between the logarithms of numbers of these organisms in soils cropped only to corn and oats was much lower, being just significant. The correlations between the actual numbers of organisms showed a similar trend to those found between the logarithms of numbers.

4. The presence of legumes in a crop rotation seems to promote a more stable flora of the organisms investigated.

5. The ammonia-oxidizing organisms and the legume bacteria studied showed similar responses to fertilizer treatments. Greater fluctuations were observed, however, in the numbers of legume bacteria.

6. The ammonia-oxidizing organisms reached their maximum numbers in the spring or early summer. The alfalfa and red clover bacteria showed no consistent seasonal fluctuations.

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BOOK REVIEW

HANDBOOK OF CHEMISTRY

By Norbert Adolph Lange, assisted by Gordon M. Forker. Sandusky, Ohio: Handbook Publishers, Inc. Ed. 2. XVI+1780 pages, illus. Fabricoid. 1937. $6.

THIS volume is a revised and enlarged one of the first edition published in 1934. To it has been added 16 new tables, while 32 of the tables in the first edition have received major or minor revision. The main body of the book is made up of 1,500 pages of chemical and physical data of every imaginable kind, the scope and comprehensiveness of which have to be seen and used to be appreciated. The remainder of the volume consists of a mathematical appendix of 249 pages compiled by Prof. R. S. Burington of the Case School of Applied Science, and an especially fine 30-page index which makes the subject matter very accessible

In size and scope this volume is unequalled by other works of its kind. The printing is exceptionally well done and the type large and clear. It is difficult to speak too highly of the work as a handbook for chemists and physicists. Although written primarily for industrial workers, anyone who has occasion to use chemical and physical data will find it extremely useful (R C. C)

AGRONOMIC AFFAIRS

ANNUAL MEETING OF SOCIETY

THE thirtieth annual meeting of the American Society of Agronomy will be held in the Hotel Stevens, Chicago, Ill., December 1, 2, and 3 The general session of the Society will be held Thursday morning, with President F D. Richey in charge of the program. Programs for the Soils Science Society of America, which also functions as the Soils Section of the American Society of Agronomy. and for the Crops Section are being arranged by their respective chairmen, Dr. Richard Bradfield and Dr. O S. Aamodt Various other organizations with agronomic interests are also meeting in Chicago at the same time.

CONFERENCE ON EDUCATIONAL BROADCASTING

THE second national conference on educational broadcasting is to be held at the Drake Hotel, Chicago, Ill., November 29, 30, and December 1, and will include discussions of the American system of broadcasting, an evaluation of broadcasting from the public point of view, an appraisal of educational broadcasting, and the future of radio, with distinguished representatives of education, the radio industry, and the radio audience leading the discussion.

The sponsors of the conference have invited the American Society of Agronomy to cooperate without financial obligation. Further information about the conference and a preliminary program may be obtained from Mr. C. S. Marsh, Executive Secretary, 744 Jackson Place, Washington, D. C.

TENTATIVE PROGRAM FOR SOIL SCIENCE SOCIETY

AN outline of the program for the annual meeting of the Soil Science Society of America which is to be held in the Stevens Hotel, Chicago, Ill., Nov. 30 to Dec. 3, is presented below:

BUSINESS MEETING

The annual business meeting and dinner will be held on Wednesday evening, December 1.

GENERAL PROGRAM

Thursday, 2:00 P.M., December 2

The Agronomic Significance of Structure in Soils

SECTION PROGRAMS

(One half-day session will be devoted to each numbered item listed below.)

Section I. Soil Physics—H. E. Middleton, *Chairman*

1. Miscellaneous papers on soil physics.
2. Papers dealing with soil moisture relationships.
3. Papers dealing with the erodibility of soils
4. Joint meeting with Section V on microscopy in soil investigations.

Section II. Soil Chemistry—S. F Thornton, *Chairman*,

1. Joint symposium with Section IV on chemical methods for determining the fertilizer needs of soils
2. Miscellaneous papers dealing with soil chemistry.
3. Miscellaneous papers dealing with soil chemistry.

Section III. Soil Microbiology—L. M. Turk, *Chairman*.

1. Joint program with the Crops Section on nitrogen fixation of leguminous plants.—E. B. Fred, *Chairman*.
2. Miscellaneous papers on soil microbiology.
3. Miscellaneous papers on soil microbiology.

Section IV. Soil Fertility—W. H. Pierre, *Chairman*.

1. Joint symposium with Section II on chemical methods for determining the fertilizer needs of soils
2. Miscellaneous papers on soil fertility.
3. Symposium on soil fertility and plant composition.

Section V. Soil Morphology, Classification, and Cartography—L. C. Wheeting, *Chairman*.

1. Technics in soil surveying.
2. Regional soil studies.
3. Land classification and soil geography.
4. Forest soil types of the United States.
5. Joint symposium with Section I on microscopy in soil investigations.

Section VI. Soil Technology—L. R. Schoenmann, *Chairman*.

1. Relationship of physical land factors.
2. Problem areas in soil conservation.
3. Rainfall, runoff, and soil losses.
4. Methods of soil sampling and measurement.

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DECOMPOSITION OF *CROTALARIA JUNCEA* UNDER FIELD CONDITIONS[1]

B. N. SINGH AND S. N. SINGH[2]

IN India the commonly used green-manuring crop, *Crotalaria juncea*, is generally sown with the onset of the rains and is plowed under when about half grown. The succeeding crop is sown in winter, in the middle of October, unless the field is prepared for sugarcane which is generally sown in the months of February and March. The interval between the turning under of the *Crotalaria juncea* and the sowing of the winter crop is intended to allow for the decomposition of the incorporated material. To a large extent the success of the following crop depends upon the degree of decomposition attained.

In a previous communication, dealing with the chemical analysis of *Crotalaria juncea*,[3] it was shown that the potential manurial efficiency of this plant is quite high, but that in common practice only a fraction of its real value is realized. The explanation for the difference between the expected and the observed manurial values of this plant seemed to lie in the part that the various plant organs contributed and suggested a further study of the rate of decomposition of these parts. Hence, this paper deals with the rapidity, order, and degree of decomposition of the different organs of *Crotalaria juncea* under field conditions.

EXPERIMENTAL TECHNIC

The experiments were conducted in lysimeters, located in the Experimental Farm area of the Institute. During the last four years all lysimeters received the same type of treatments. Each year they were planted with wheat in winter and left fallow during the rest of the year. No artificial fertilizer or organic manure were applied.

In June 1936 *Crotalaria juncea* was sown broadcast in an adjoining field. In the last week of August the plants were dug, the various parts separated, and mechanically disintegrated and added to different lysimeters. At regular intervals the soil

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication May 13, 1937.

[2]Director of the Institute and Research Scholar, respectively.

[3]SINGH, B. N., and SINGH, S. N. Analysis of *Crotalaria juncea* with special reference to its use in green-manuring and fibre-production. Jour. Amer. Soc. Agron., 28: 216–227. 1936.

was watered so as to maintain the moisture content between 15 and 25% throughout the period of the experiment.

Before burying the plant parts in the lysimeters their fresh weights were recorded. A known weight of each of these samples was then incubated at 100°C to a constant weight, and thus the total dry matter added to each lysimeter calculated on an acre basis. At successive weekly intervals soil samples in rectangular blocks were taken from the lysimeters containing the different plant organs and the dry weights of the residual plant parts were estimated. This was assumed to be a satisfactory criterion of decomposition under field conditions and gave the loss in total dry weight of the weighable organic matter incorporated in the soil.[4] The weighable organic matter was that left on a 15-mesh sieve which was washed and dried to constant weight and then calculated on an acre basis.

The soil samples were taken from four different depths, *viz*. 6, 9, 12, and 18 inches. They were air dried and sieved to pass through a 1-mm sieve. They were analysed for both total and available nitrogen because of the significant rôle nitrogen plays in determining soil fertility. Modified Kjeldahl and Devarda alloy methods[5] were employed in determining total and available nitrogen, respectively.

EXPERIMENTAL FINDINGS

WEIGHABLE ORGANIC MATTER

On August 21, 1936, the various plant organs were separated and weighed on an acre basis before incorporation with the soil. The data in Table 1 show that altogether 15,300 pounds per acre of dry matter of *Crotalaria juncea* were buried in the soil, the major part of which was represented by the stems. The leaves formed approximately one-fifth of the stem weight, while the roots comprised only one-eighth.

TABLE 1.—*The organic matter present at successive stages during decomposition of various parts of Crotalaria juncea under field conditions.*

Plant part	Date of sampling								
	Aug. 21	Aug. 28	Sept. 4	Sept. 11	Sept. 18	Sept. 23	Oct. 2	Oct. 9	Oct. 16
	In Pounds per Acre								
Leaves...	2,400	2,150	1,416	957	420	205	55	—	—
Stems. .	11,500	10,955	9,722	8,105	6,998	6,005	5,788	4,820	4,315
Roots. . .	1,400	1,315	1,195	905	712	605	415	307	275
Whole plant	15,300	14,420	12,333	9,967	8,130	6,815	6,258	5,127	4,590
	In Percentage								
Leaves...	100.0	89.6	59.0	39.8	17.5	8.5	2.5	—	—
Stems....	100.0	95.2	84.5	70.4	60.8	52.2	50.3	41.0	37.5
Roots....	100.0	94.0	85.3	64.6	50.8	43.2	29.6	21.9	19.6
Whole plant...	100.0	94.2	80.6	65.1	53.1	44.5	40.9	33.5	30.0

[4]TAM, R. K., and MAGISTAD, O. C. Chemical changes during decomposition of pine-apple trash under field conditions. Soil Science, 41:315–327. 1936.

[5]ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and tentative methods of analysis. Washington, D. C. Ed. 3. 1930.

The quantity of the weighable organic matter decreased continuously with the length of the decomposition period. The leaves decomposed at a much faster rate than either the stems or the roots. The major part of the leaves decomposed within a period of four weeks after burial and disappeared completely during the next two weeks. At the end of the experiment 19.6% of the roots and 37.5% of the stems were found undecomposed.

Considering the decomposition of the entire plant, calculations of the weights obtained at the start of the experiment and those at the end of eight weeks show that only 70% of the total dry matter is decomposed, while the remaining 30% is unaffected.

NITROGEN VALUE

The amount of nitrogen in the soil both for available and total nitrogen shows a marked difference with the nature of the incorporated organic matter (Table 2). Leaves contribute the most to the soil in terms of nitrogen, with the roots and stems next in order. The quantity of available nitrogen in the case of the leaves increased from 51 p.p.m. at the start of the experiment to 170 p.p.m. on September 11 in the upper 6 inches of soil.

TABLE 2.—*Quantitative changes in the nitrogen content of the soil at different depths during decomposition of various parts of Crotalaria juncea.*

Sampling date	Depth of sampling											
	Leaves				Stems				Roots			
	6 in.	9 in.	12 in	18 in.	6 in.	9 in.	12 in.	18 in.	6 in	9 in.	12 in.	18 in.
	Available Nitrogen, p. p. m.											
Original	51	44	25	9	—	—	—	—	—	—	—	—
Aug. 21	53	44	26	11	51	45	24	9	52	45	25	9
Aug. 28	65	46	26	9	55	44	24	9	60	46	26	10
Sept. 4	125	50	25	10	70	46	25	10	75	47	27	12
Sept. 11	170	53	27	9	76	45	25	9	90	46	26	10
Sept. 18	168	60	28	11	82	48	26	10	93	49	31	12
Sept. 25	145	62	35	11	82	49	26	10	99	55	30	13
Oct. 2	105	70	40	13	86	51	30	12	107	59	33	14
Oct 9	77	76	48	21	95	53	37	15	115	61	37	16
Oct. 16	55	83	52	26	105	57	40	19	111	65	45	18
	Total Nitrogen, p.p.m.											
Original	1,250	1,155	975	460	—	—	—	—	—	—	—	—
Aug. 21	1,375	1,175	975	455	1,340	1,110	930	445	1,360	1,175	975	450
Aug. 28	1,560	1,225	995	505	1,355	1,155	925	450	1,425	1,170	1,000	505
Sept. 4	1,935	1,220	1,075	525	1,475	1,180	935	440	1,495	1,220	1,055	495
Sept. 11	2,115	1,260	1,050	495	1,480	1,185	930	470	1,525	1,250	1,095	525
Sept. 18	2,075	1,310	1,075	515	1,495	1,205	955	495	1,565	1,345	1,105	543
Sept. 25	1,935	1,435	1,100	525	1,555	1,225	980	505	1,630	1,360	1,110	535
Oct. 2	1,565	1,440	1,175	545	1,625	1,250	970	480	1,745	1,405	1,140	545
Oct. 9	1,505	1,455	1,375	560	1,715	1,275	1,000	515	1,875	1,440	1,155	545
Oct. 16	1,490	1,525	1,380	555	1,935	1,305	1,025	515	2,010	1,490	1,190	550

The total nitrogen in the top soil also increased and reached its maximum on the same date. In the following week the amount of available nitrogen was more or less constant, but after that both total and available nitrogen underwent a constant diminution till the end of the experiment when the values were only slightly higher than at the start. On the other hand, in the deeper soil layers, although there was an apparent fall from one depth to the other, the nitrogen content increased regularly, and at the end of eight weeks was twice as high as originally, especially in the case of available nitrogen. The increase in total nitrogen, although quite significant, was not so great. In the sub-soil as represented by the 18-inch layer available nitrogen fluctuated within a very narrow range during the major part of the decomposition period, but towards the close of the period it shot up and attained a very high level.

In the case of the stems and roots incorporated with the soil the quantities of both available and total nitrogen were always less than in the case of the leaves except in the top soil during the later weeks where a decline was observed in the latter case. With the stems and roots there was an increase till the end, but even after eight weeks decomposition the maximum values for available nitrogen never attained the same level as in the case of the leaves. Total nitrogen during the last week reached very nearly the maximum level attained by the leaves. The total nitrogen decreased with the depth of the soil, but at each level increased with the period of decomposition.

DISCUSSION

From the foregoing observations it is apparent that of all the parts of *Crotalaria juncea* studied, the leaves were the most readily decomposed and their constituents made available in the soil. Within a period of four weeks only traces of the leaves were left undecomposed, and it was at this period they contributed the most to the fertility of the soil both in terms of available and total nitrogen. The decline in nitrogen after this point may be attributed to the effect of leaching and to the loss of ammonia compounds through volatilization. To bring about complete decomposition of the incorporated material, the maintenance of fairly high moisture content of the soil was necessary, and this resulted in leaching out the constituents already present in a liquid phase as a result of the early decomposition of the leaves. The increase in the nitrogen content of the lower layers of the soil is proof of the above statement.

The roots and the stems seemed to offer greater resistance to decomposition than did the leaves, due possibly to the nature of the organic matter accumulated in these parts during growth. As previously shown,[6] the leaves contain the simpler carbohydrates, while the roots and stems contain compounds of a higher degree of complexity which are more resistant to attacks by soil micro-organisms with the result that a large fraction of the stems and roots is left undecomposed at the time of sowing the following crop. This undecomposed residue not only represents a loss of nitrogen from these

[6]See footnote 3.

parts of the plant, but it also forms a substratum for attack by white ants in the growing crop. Moreover by the end of the decomposition period of eight weeks the leaves have completely disappeared in the soil and their constituents are more or less leached out. If more water is added to facilitate the decomposition of the stems and roots, the greater is this leaching effect. The present method of green-manuring with *Crotalaria juncea*, therefore, is not free from serious defects not only because a large part of the plant remains unaffected, but also because the constituents which are made available by the decomposition of the leaves are lost without materially contributing to the succeeding crop, thus resulting in a wide difference between the expected and the observed values of the green-manuring efficiency of this plant.

SUMMARY AND CONCLUSION

This investigation involved a study of the decomposition of the various parts of *Crotalaria juncea* under field conditions to throw light on methods of green-manuring. The decomposition under field conditions was measured in terms of the weighable organic matter left undecomposed in the soil at successive intervals and the amount of available and total nitrogen added to the soil.

The leaves were most rapidly decomposed, with the roots and stems next in order. The complete decomposition of the leaves required not more than six weeks and the major part was decomposed within four weeks. On the other hand, after a period of eight weeks, 37.5% of the stems and 19.6% of the roots remained unattacked by the soil micro-organisms. Considering the plant as a whole, at the end of the experimental period 30% of the total dry weight was found to be undecomposed.

The leaves contributed most to the soil in terms of both available and total nitrogen, the maximum being attained in the 6-inch layer after four weeks of burial. Thereafter a concomitant decrease in nitrogen was observed till the end of the observational period, while in the sub-soil layers no such reduction was noticed.

The effect of leaching was apparent in all cases but more especially in the case of the leaves. Nitrogen seemed to penetrate deep into the soil at a rapid rate.

In the light of these investigations more suitable methods of green-manuring with *Crotolaria juncea* must necessarily be developed and standardized. Work along this line is now in progress at the Institute.

A PRELIMINARY STUDY OF THE RELATIONSHIP BETWEEN VITAMIN C CONTENT AND INCREASED GROWTH RESULTING FROM FERTILIZER APPLICATIONS[1]

B. ISGUR AND C. R. FELLERS[2]

WITH increased yields due to the extensive use of commercial fertilizers, especially on truck crop farms, it becomes desirable that research workers investigate the influence of these fertilizer materials on the nutritive value of the plant.

Pfützer and Pfaff (1)[3] found that the vitamin C content of many plants was relatively unaffected by fertilizer treatment, though the plants showing the highest yields were also highest in vitamin C content. Luettmerding (2) showed that in germinating oats, peas, and wheat, vitamin C formation was accelerated in proportion to the acidity of the medium. Hahn and Gorbing (3) found that the amount and type of fertilizer used have a marked effect on vitamin C content of spinach. A fertilizer well balanced in nitrogen, phosphorus, and potash gave the highest vitamin C. An unbalanced fertilizer gave crops of low vitamin C content. The greatest decrease in vitamin C occurred when excess nitrogen was present.

Fellers, Young, Isham, and Clague (4) reported that variations in the amount of potash and nitrogen used in the fertilization of asparagus did not appreciably affect the vitamin C or A content of this crop. The antiscorbutic ratings as determined in this experiment were as follows: Asparagus receiving high nitrogen fertilization was slightly better than that from a normal completely fertilized plat and the latter was somewhat superior to asparagus grown under high potash fertilization. There was a slightly greater growth rate in animals fed on the no-potash asparagus than in those fed the high potash plants.

In England, two varieties of apples from high and low nitrogen plats were tested by Bracewell, Wallace, and Zilva (5). They found that the nitrogen content of the apples did not correlate with the vitamin C content. That the nature of the soil had no measurable effect on the antiscorbutic potency of oranges was reported by Bracewell and Zilva (6). Potter and Overholser (7) and Batchelder (8) found that Winesap apples from trees receiving applications of a complete fertilizer were a better source of vitamin C for guinea pigs fed 5 grams daily than apples from trees not so fertilized.

EXPERIMENTAL METHODS

It was decided to investigate the effect of fertilizer treatment on the vitamin C content of New Zealand spinach (*Beta vulgaris*) and Swiss chard (*Tetrognia expansa*). Both species of plants are grown for their leaves and thus the entire aerial portion could be used for ascorbic acid (vitamin C) determinations, thereby lessening the error which usually accompanies the separation of a plant into several

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[3]Figures in parenthesis refer to "Literature Cited", p. 893.

parts for chemical analysis. Also, these plants belong to different botanical families, *viz.*, Chenopodioceae and Ficoideae, respectively, thus facilitating any generalization which might possibly suggest itself.

One-gallon glazed earthenware crocks were used and 10 plants grown in each crock. Each treatment was run in duplicate and the plants were harvested as soon as they began to show signs of maturity. White sand, obtained from the Berkshire Sand Company, was washed with dilute hydrochloric acid and the acid completely leached out by means of tap water. Fifteen pounds of washed sand were used in each crock to which was added a definite amount of fertilizer. Water was added to 60% of the water-holding capacity of the sand and kept at that content by daily additions.

Nine fertilizer treatments were used for each species, making 36 crocks in all. The treatments consisted of additions of N, P, and K used at high, medium, and low levels of fertilization.

The nitrogen was supplied in the form of ammonium sulfate (20% N) and sodium nitrate, (15% N), equal amounts of N being supplied from each source. The phosphorus was in the form of superphosphate (16% P_2O_5) and the potash in the form of KCl (48% K_2O). Magnesium sulfate was supplied in equal amounts to each pot. Table 1 shows the amounts applied in terms of pounds to the acre—6 inches.[4]

The dye titration method of ascorbic acid (vitamin C) determination, as modified by Bessey and King (9), was used.

A weighed amount of plant material (about 5 grams) was placed in a mortar and the tissue thoroughly macerated in the presence of trichloroacetic acid. Small portions of acid-washed white sand were added to facilitate the trituration process When the plant material was sufficiently ground, more trichloroacetic acid was added to make the total acid content 50 cc (8% acid solution) The material was then centrifuged in 50-cc tubes for 10 minutes at 2,000 r. p. m. and the clear liquid decanted. A small quantity of acid was then introduced into the centrifuge tube and a second extraction was made to remove any vitamin C which remained behind in the tissues. It was found that two extractions removed practically all the vitamin C. The decanted liquid was then diluted to 200 cc and 50-cc aliquots titrated with 2,6-dichlorophenolindophenol dye solution. Duplicate determinations were made on all samples.

Several comparisons of the biological method of vitamin C assay and the above dye titration technic (10, 11) have been reported in the case of peas, spinach, and other plant materials and concordant results have been obtained by both methods. It is believed that the dye titration results for l-ascorbic acid are truly representative of the vitamin C content of the plant.

DISCUSSION OF RESULTS

Table 1 gives a resumé of the results both on the yield and on the ascorbic acid (vitamin C) content of each treatment.

In general, in the case of Swiss chard, the ascorbic acid content per gram of dry matter seems to increase as the yield increases. An apparent exception is treatment A, where, with a yield of 6.45 grams, there is an ascorbic acid content of 4.06 mg per gram of dry material. However, on the whole, increased amounts of fertilizer materials

[4]For the purposes of this work, it was assumed that the surface 6 inches of an acre of soil weighs 2,000,000 pounds.

TABLE 1.—*Effect of fertilizer treatment on the ascorbic acid (vitamin C) content of Swiss chard and New Zealand spinach.*

Treatment	Pounds per acre			Swiss chard		New Zealand spinach	
	N	P_2O_5	K_2O	Dry weight, grams	Cv/ gram*	Dry weight, grams	Cv/ gram*
A	230	240	57.6	6.45	4.06	5.20	3.48
B	115	240	57.6	7.43	3.58	4.80	2.86
C	115	120	115.2	7.01	3.25	4.33	3.86
D	230	240	115.2	8.91	4.01	4.04	3.68
E	115	120	57.6	6.41	2.14	3.72	3.64
F	15	120	57.6	4.02	2.42	2.62	4 37
G	115	8	57.6	0.50	2.95	1.01	3.54
H	115	120	7.68	5.95	3.84	5.21	2.82
I	15	8	7.68	1.86	1.73	1.15	3.57

*Mg ascorbic acid (vitamin C) per gram dry matter.

added to Swiss chard appear to increase the ascorbic acid content to some extent. Greater growth and vigor seem to be associated with high ascorbic acid content. High nitrogen treatments in particular seemed to give the highest ascorbic acid values. It should be pointed out that too few determinations were made to draw definite conclusions. Also, in the case of New Zealand spinach, high N fertilization did not result in increased ascorbic acid content of this plant. No definite correlations could be found in either crop between P or K treatments and the content of ascorbic acid.

The two crops behaved differently under the same conditions in this experiment. The New Zealand spinach showed relatively little variation with fertilizer treatment, while the Swiss chard was much more variable.

In the case of the New Zealand spinach, there seems to be little, if any, correlation between the yield and the ascorbic acid content of the plants. Five of the nine treatments gave ascorbic acid contents which lie between 3.48 and 3.68 mg per gram of dry matter, while a sixth contains 3.86 mg ascorbic acid per gram of dry matter.

While it is possible that some of the differences in ascorbic acid content may be caused by the varying proportions of the fertilizing materials present in each treatment, the data do not prove this thesis. Thus, in the case of treatment A, although the yield is not the maximum for the nine treatments, the high vitamin C content may be due to the fact that for this plant high nitrogen and medium quantities of phosphorus and potassium are necessary to bring out the highest yield of ascorbic acid (vitamin C). It seems that fertilizer treatments may affect vitamin C formation differently for different species of plants.

CONCLUSIONS

1. In general, increases in yield of Swiss chard caused by fertilizer application were accompanied by increases in the ascorbic acid (vitamin C) content. The high nitrogen treatments resulted in the highest yields of ascorbic acid.

2. Increases in yield of New Zealand spinach caused by fertilizer applications were not accompanied by any increase in the ascorbic acid content.

3. There is no evidence that the use of properly balanced fertilizer decreases the ascorbic acid content of plants.

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A WEIGHT ESTIMATE METHOD FOR THE DETERMINATION OF RANGE OR PASTURE PRODUCTION[1]

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ESTIMATES of plant cover density have been and are still being used as a basis for the determination of grazing capacity. However, experiments carried on by the Intermountain Forest and Range Experiment Station have shown variations to occur in the grazing capacity of pastures between that calculated from ground cover or plant density surveys and that derived by actual grazing trials.

Since accurate grazing capacity estimates are essential to the formulation of sound policies for the maintenance or increase of range forage, these variations between calculated and actual grazing capacities found on native sagebrush-wheatgrass ranges were deemed serious enough to warrant a study of methods used in forage inventory.

It was the purpose of this study (a) to examine existing available methods of estimating grazing capacity and to select the most satisfactory method or, in the event that none was wholly desirable, to design a new method; and (b) to test the selected method in conjunction with estimates of density to determine the relative accuracy, personal error, and tendency for lesser dispersal of estimates.

FORAGE INVENTORY METHODS

Pasture and range analyses probably date back to the end of the nineteenth century. Since that time a widely diversified group of methods have evolved. Stapledon (18)[3] introduced the specific frequency method and made extensive use of the percentage productivity method. Davies (4) adapted percentage estimation to determinations of percentage frequency and productivity. Levy (13) perfected the point method of pasture analysis. About the same time, Clements (2) began using square-meter quadrats. Sarvis (16), using list and chart methods, calculated percentage ground cover. Salcedo (15), Knott, *et al.* (11), and Davies and Trumble (3) used animal units in determining carrying capacity. DeVries (5) used the "rank method". Stewart and Hutchings (19) advanced the "point-observation-plot" method of determining vegetative ground cover.

Two of these methods of forage inventory, the "percentage-productivity-estimate method" and the "point-observation-plot method", are especially noteworthy from the standpoint of the principles embodied.

"Percentage productivity estimation" was discussed by Davies (4) and adapted by Beruldsen and Morgan (1), Davies and Trumble

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[3]Figures in parenthesis refer to "Literature Cited", p. 904.

(3), and Klapp (10). Various modifications of this method have been tried by Larin, *et al.* (12) and by Hanson (7). With this method, forage yield is sampled by clipping and weighing herbage from several randomized plots. Percentage composition by weight is then estimated either from the clipped herbage or by a spatially repeated estimate of percentage productivity on unclipped areas. These figures applied to the yield from clipped plots give the floristic composition of the sampled area in terms of yield. Data secured with this method have been proved accurate by Beruldsen and Morgan (1), and since an absolute check on estimates by weight analysis is possible, the method is widely recommended. This method is for use on purely randomized temporary plots, but since clipping results in injury to plants, it cannot be employed on sample plots located permanently for the purpose of tracing the reaction of native vegetation to systems of grazing or climate. In addition, the method becomes too laborious to sample yield adequately on native sagebrush-wheatgrass range areas where shrubby vegetation predominates.

The "point-observation-plot method" (19) involves a count of square-foot vegetative ground cover (density) by species on small, fully replicated, mechanically located plots whose areas are in multiples of 100-square feet. A square-foot ground cover is, when viewed from directly above, 1 square foot of ground entirely covered by undisturbed current vegetative growth. Mechanics of the method are easily learned and estimates can be made rapidly. Data secured are in terms of percentage ground cover by species. Principles of plot location, comparative surveys, and replication are fully discussed by Stewart and Hutchings (19), but since estimates are in terms of ground cover, data secured by this method are not fully satisfactory for grazing-capacity studies.

THE WEIGHT-ESTIMATE METHOD

In view of the fact that no one method was found to be entirely satisfactory, a weight estimate method was designed embodying the most desirable features of the percentage-productivity and the point-observation-plot methods. When using the weight-estimate method, estimates are made on plots located either in a gridiron or patternized arrangement of the point-observation-plot method or the randomized arrangement of the percentage productivity method. In common with the latter method, yield and floristic composition are recorded in units of green or dry weight of the current aerial herbage growth.

PROCEDURE IN CONDUCTING TEST

Two areas in southeastern Idaho, one dominantly grass and the other weed, were chosen upon which to test the methods. On each area 20 circular 100 square-foot plots were located in such a manner that each contained all three selected species.

The first area was located on a high mountainous summer range near Spencer, Idaho, where the following species were found: *Geranium viscosissimum*, a tufted perennial of moderate height (25–60 cm) with leaves largely all basal; *Rudbeckia occidentalis*, a tall tufted perennial (50–200 cm) with caulescent leaves on heavy

woody stems; and *Arnica cordifolia*, a low perennial (20–60 cm) from rootstocks in this locality with leaves chiefly basal. These were chosen because they represent three common types of weed growth.

The second area was located near St. Anthony, Idaho, in a typical sagebrush-wheatgrass range area where were found *Agropyron dasystachyum*, a perennial rootstock grass of moderate height (40–80 cm); *Stipa columbiana*, a tufted perennial of moderate height; and *Carex filifolia*, a low densely caespitose perennial with filiform leaves (8–12 cm). These were chosen because they represented three common types of grass growth.

Three individuals, trained on areas apart from the trial plots, were used to estimate weight and density at the two areas. No checking nor comparisons between individuals were made throughout the test. Each estimated all three species on each plot and then moved to the next. Upon the completion of all weight and density estimates, herbage was clipped, segregated by species, and weights recorded.

Covariance (6, page 275) was used in analysis of the data to test the degree of association between estimates and actual clipped weights, and, by subdivision of error into its component parts, to determine whether the error was personal or mechanical. Since the data were not truly orthogonal, it was impossible to secure man-species interaction. Thus in Table 2, the total sum of squares due to differences in man-species means and regressions plus residual around man-species regressions is equal to the error of estimation (departure from general regression). Variability and relative variability were tested using the standard deviation and coefficient of variability (8, page 36).

RESULTS

Estimates of weight are accurate and approach closely the actual mean herbage weights. (See summary and analysis of data in Tables 1 and 2.) Weeds, apparently, can be more easily estimated than grasses, since in only two cases does the average difference between estimated and actual clipped weight exceed 10%; whereas, with grasses, out of nine average differences, four exceed 15%. Two of these differences, 15 and 20% in the estimates of *Agropyron dasystachyum*, are only indicative of the difficulty that is experienced with any character of estimate on rootstock grasses. In the case of *Carex filifolia* all three average estimates exceed a difference of 10%. Average actual weight per plot of *C. filifolia* was only 26.8 grams. Since it is hardy possible to distinguish differences in gram estimates to a finer degree than 10 grams, a decision between 10 and 20 grams or between 20 and 30 grams might be responsible for an error of 33 to 100%. Thus, it is seen that for a test not enough latitude in weight was provided in the case of *C. filifolia* to allow freedom of judgment. However, such cases occur constantly in the field and these errors are indicative of what might be expected in estimates on species of lesser weight per plot.

Estimates of weight not only closely approach actual weights in the means, but a high correlation ($R^2 = .9197$, table 2) between estimates and actual weights indicates that individual estimates are rather reliable in indicating actual herbage production on individual plots.

A comparison of analyses (Table 2) of actual weight to estimates of

TABLE 1.—*Summary of mean actual weights, mean weight estimates, and mean density estimates for 20 plots.*

Species	Actual clipped weights*	Weight estimates by individuals*			Density estimates by†		
		1	2	3	1	2	3
Geranium viscosissimum	710.5	675.5	681.0	728.5	4.55	4.75	4.99
Rudbeckia occidentalis..	1,628 5	1,661.0	1,497.0	1,313.2	6.36	6.56	6.12
Arnica cordifolia	142.8	141.0	137.0	140.2	3.65	3.45	3.30
Agropyron dasystachyum	577.8	665.0	601.0	460.0	1.12	1.36	1.58
Stipa columbiana .. .	235.0	232.8	251.0	252.5	1.01	0.95	1.14
Carex filifolia.	26.8	22.2	30 0	20.2	0.86	0.99	1.00

*Weight is expressed in grams green weight.
†Density expressed in square feet.

weight and actual weight as compared to estimates of density shows that estimates of weight are superior to estimates of density in indicating the weight of herbage produced. As contrasted to a residual of 8% of the total sum of squares unaccounted for by the regression of weight on weight estimates, 35% of the total sum of squares remains unaccounted for by density estimates. These departures from regression constitute errors of estimate with both methods. A subdivision of this error into its component parts (Tables 2 and 3) shows that with weight estimates, the major portion of the accountable error lies in the difference between means and slopes of regression for different individuals. With density estimates most of the accountable error lies within the differences between means and slopes of regressions for different species and nearly twice as much residual error remains unaccounted for.

Error of weight estimates is largely personal; that is, it lies in the difference between individual mean estimates and individual regression slopes. With density estimates, however, the error lies not so much in and between individuals as with the varying relationships between the density and the weight of different species. Since the relationship between density and herbage weight is not constant ($F = 18.92$ which exceeds a probability of 1 in 100 that differences between slopes of species regressions are significant), the error lies in the basic concept of the method and cannot be easily eliminated. The exact nature of this varying relationship is shown by Table 4 where yield in green weight per square foot density is shown to vary from 28.5 grams with *Carex filifolia* to 428.0 grams for *Agropyron dasystachyum*, and in dry weight from 36 grams for *Tetradymia canescens inermis* to 107 grams for *Gutierrezia sarothrae*.

These wide variations in green and dry weights per square foot of density (Table 4) confirm Standing's (17) conclusions that different species produce different amounts of herbage per unit area and that computed forage acres based on a survey of plant cover density are greatly influenced by the species making up the cover. Such inconsistencies make it difficult to construct accurate plans for and adjustments in range use. Since weight estimates approximate closely the yield per unit area, yield on adjacent areas calculated from weight

TABLE 2.—*Relative reliability of weight and density estimates in indicating yield of green herbage.*

Due to	D.F.	Sum squares	Mean square	F
Actual Weight on Weight Estimates				
General regression—actual on estimate				
Departures from general regression (error of estimate)	1	152,493,926	——	——
Error due to:				
Difference among man means	2	461,324	230,662	8.04*
Differences among man regressions	2	1,482,984	741,492	25.83*
Differences among species means	5	200,781	40,156	1.40
Difference among species regressions	5	465,218	93,044	3.24*
Difference among man-species means	17	2,179,562	128,210	4.47*
Differences among man-species regressions	17	1,828,898	107,582	3.75*
Residual error unaccountable for (around man-species regressions)	324	9,300,624	28,706	——
Total sum squares	359	165,803,010		
Actual Weight on Density Estimates				
General regression—actual on estimate	1	107,090,635	——	——
Departures from general regression (error of estimate)				
Error due to:				
Difference among man means	2	65,678	32,839	.64
Differences among man regressions	2	419,096	209,548	4.10
Differences among species means	5	36,359,826	7,271,965	142.31*
Differences among species regressions	5	4,833,517	966,703	18.92*
Difference among man-species means	17	36,709,775	2,159,399	42.26*
Difference among man-species regressions	17	5,446,488	320,382	6.27*
Residual error unaccountable for (around man-species regressions)	324	16,556,112	51,099	——
Total sum squares	359	165,803,010		

*Probability exceeds 1 in 100 that differences are significant.

TABLE 3.—*Allocation of errors in using density and weight estimates for indicating actual weight.*

Errors due to differences among	Sum of squares		Percentage of total sum squares	
	Weight	Density	Weight	Density
Man means	461,324	65,678	0.278	0.040
Man regressions	1,482,984	419,096	0.894	0.253
Species means	200,781	36,359,826	0.121	21.930
Species regressions	465,218	4,833,517	0.281	2.915
Species-man means	2,179,562	36,709,775	1.315	22.141
Species-man regressions	1,828,898	5,446,488	1.103	3.285
Error unaccountable for	9,300,624	16,556,112	5.609	9.885
Departure from regression (total error)	13,309,084	58,712,375	8.027	35.411
Total sum squares	165,803,010			

estimates should be closely comparable and furnish a fairly sound basis for a more comprehensive program of adjustments or plans.

TABLE 4.—*Variations in weight yield per square-foot density.*

Species*	Green weight per sq. ft., grams	Species†	Weight per square foot, grams	
			Green	Dry
Rudbeckia occidentalis	261.4	*Agropyron spicatum*	98	44
Geranium viscosissimum	153.1	*Oryzopsis hymenoides*	98	48
Arnica cordifolia	38.3	*Crepis acuminata*	349	87
Agropyron dasystachyum	428.0	*Gutierrezia sarothrae*	224	107
Stipa columbiana	223.8	*Helianthella uniflora*	239	99
Carex filifolia	28.5	*Artemisia tridentata*	142	60
		Tetradymia canescens inermis	99	36

*This group calculated from the mean density estimates and actual clipped green weights presented in Table 1. No moisture percentages available

†These data calculated from approximately 1,000 estimates of density and weight. Dry weight per square foot derived by the use of shrinkage percentage applied to the green weight Moisture content or shrinkage percentage secured from samples collected during the study.

As shown by larger sums of squares (Tables 2 and 3) due to differences between man means and man regressions, weight estimates are subject to slightly more personal error than density estimates. This would be normally expected since with the weight estimate method a different unit is used for each species; whereas, with the density method only one unit is used for all. More intensive training of the personnel and careful observation on their part may be found to correct much of this error.

An inherent error in any method employing eye estimates is that the individual estimates tend to show less relative dispersion than the actual quantities being estimated; that is, estimates cluster around the mean, the error of estimate being positive for small quantities and negative for large quantities.

Relative dispersion of weight and density estimates and of actual clipped weights per plot are presented in Table 5. Since weight and density are two different units of measurement, the coefficient of variability was used to test relative dispersal in estimates by the two methods.

There is a distinct tendency of both weight and density estimates toward less dispersal than actual weights. With weight estimates this

TABLE 5.—*Relative dispersal of actual weights and of estimates of weight and density.*

All species	Actual clipped weights, grams	Weight estimates, grams	Density estimates, sq. ft.
Mean	553.5	528.3	2.986
S.D.*	678.6	601.0	2.690
C.V.†	122.6	113.8	90.1

*Standard deviation.
†Coefficient of variability.

deficiency is slight, but with density estimates, as shown by the coefficient of variation, dispersal of estimates is as much as 30% less.

DISCUSSION

The following discussion is concerned with weight estimates versus estimates of density for indicating the amount of herbage on an area. As shown by data presented, a comparison of the two methods may be stated as follows:

1. For any one plant species, weight estimates are slightly but significantly superior to density estimates in indicating differences in herbage productivity on different areas (Table 2).
2. For plant species differing in growth habit and stature, weight estimates are definitely superior to density estimates in indicating herbage production (Tables 2 and 4).
3. Weight estimates are slightly more subject to personal error than density estimates (Table 2).
4. Weight estimates fluctuate equally as much as the actual values but density estimates do not (Table 5).

Since the weight estimate method provides an impersonal check on estimates, personal error may be reduced by conscientious training and careful observation. However, with density estimates, the major error is mechanical, due to the fact that the relationship between density and weight of herbage is not constant. Such an error cannot be readily eliminated. This, together with the fact that density estimates are not subject to an accurate check free from personal error, should be carefully considered when studies of grazing capacity are being undertaken. It is essential to the primary calculation of grazing capacity from forage inventory and palatability and the subsequent check-up by percentage utilization that forage inventory, palatability, and percentage utilization be expressed in the same basic terms, preferably units of volume. When either palatability ratings or percentage utilization are applied to density of plant cover, the product expressed in terms of utilization or palatability of a plane surface is meaningless and difficult for a person not technically trained to understand. Weight estimates provide the essential uniformity of basis of expression.

Since the unit of measurement used in ground cover or density surveys is not generally understood by the average layman and since it is not of such nature that animal-day requirements may be correlated with standard feeding rations, correlation of two phases of the same industry, range and livestock husbandry, is prevented. However, resultant data from weight estimates are actually in terms similar to those used in feeding trials, i. e., pounds, tons or kilograms, and are easily interpreted by the average layman. By the use of a weight basis, the amount of feed and forage preference per animal unit can be calculated. Thus, forage-acre requirement, an intangible term difficult of conception, may be expressed in pounds of feed per animal day.

As with density estimates, abundant replication is facilitated by the rapidity with which weight estimates can be made. In the sagebrush-wheatgrass range type, herbage weight can be estimated by species on

from 30 to 50 plots per man-day. Thus, the decreased precision of single eye estimate is more than outweighed by abundant replication. Where the number of plots necessary to sample the heterogeneity of vegetation is further augmented by that needed to sample uneven grazing use, more exact laborious measurement methods require excessive time or personnel and estimation methods may be found considerably more useful and accurate where time is a critical factor.

Because the use of weight estimates is in a formulative stage of development and because this method has not been tried on a sufficiently large number of areas, it is not advocated for universal use; however, it is especially worthy of consideration in pasture, paddock, or open range studies where recurrent yearly forage inventories are necessary and where correlation with actual grazing capacity is essential. With further simplification and additional tests under more diverse conditions, this method may be adapted to more extensive studies and wider usage.

THE WEIGHT ESTIMATE METHOD FOR FIELD USE

Since no change is necessary in principles set forth by the point-observation-plot method for use with weight estimates, principles of plot size, location, and field plot technic need not be rediscussed. Estimates of productivity by the weight estimate method are made on plots located in a gridiron or patternized arrangement or on purely randomized plots. Yield and floristic composition of the total current growth of the entire aerial portion of the plant are recorded in units of green or dry weight.

The most suitable number, size, shape, and manner of location of plots are dependent upon the type of vegetation to be studied and should be determined by trial before the study is initiated. Weight estimates can be used on any size or shape of plots.

Equipment required to conduct forage inventories by the weight estimate method include a set of spring scales sensitive to the nearest 10 grams and small enough to be placed in a pocket, a pair of scissors or shears with a 4- to 6-inch blade, a cloth or paper sack, and the ordinary equipment needed for marking out the circular plots, recording data, and keeping direction.

Prior to making estimates on any area or in any season each estimator should spend several days checking estimates on the same type of vegetation upon which future work is to be done. This period of training may be profitably extended to a week in the case of entirely untrained individuals. Training, if a spring scale is provided for each, is done as well individually as collectively, since after the first hour nothing is to be gained by collective training except with shrubby species or species difficult to clip. First, estimate the weight of either one or several plants of a single species, attempting from the first to define a 10-, 20-, 50-, or 100-gram unit. Count the herbage in terms of such units. Then clip and weigh herbage to determine the error of the estimate. After each estimate the individual should attempt to alter the size of his unit to conform with the last weight check made for that particular area. Train on one species at a time. While working

on the second or third species, it is well to refer back frequently to the species formerly studied. Before completion of the training period, after units for all species have been defined to the satisfaction of the individual estimator or chief of party, it is advisable to check a few times on sample plots of the same size as those selected for study of the area.

In conducting an actual forage inventory of an area, carry the same equipment used in training. In estimating, the same units defined in training, or multiples of them, should be used and herbage counted by species and recorded. It is usually sufficient to record weight to the nearest 10 grams. If plots are to be permanent, estimates can be checked on vegetation around the outside of the plot.

During the inventory of an area, each day all individuals should make estimates of herbage on the same temporary plots. From 10 to 20% as many plots should be estimated in this manner as are estimated by each individual per day. These plots are then clipped and a permanent record made of each individual's estimates and of the actual green weights. From these data can be calculated a regression by species for determining actual weights from estimated weight for any individual at any date or on any area. In the case of appreciable discrepancies between estimates and actual weights, these regressions can be used to make adjustments for such differences. This record will not only serve to make adjustments, but it will present an actual record of the performance of each estimator. Ilvessalo (9) used this method in forest surveys of Finland and found it very accurate where adjustments of ocular estimates were necessary. The clipped herbage from temporary plots may be retained for the determination of herbage moisture content.

Two difficulties found in the adaptability of the weight estimate method, *viz.*, (a) the differences in herbage moisture content at different stages of growth and at the time of estimate in different years, and (b) the inaccuracies due to grazing off of some of the herbage prior to the time of estimate, may be overcome by the following methods:

Herbage moisture content may be evaluated for all species by recording the green weight of herbage samples taken at the time of daily checking and the weights after the samples have been oven-dried. If an oven is not available, air-dry weights at the end of the season may be substituted. From these data the percentage moisture content of the herbage during the period of estimation can be calculated and the difference in estimated weights due to differences in moisture content can be adjusted between season, location, or year. If productivity is expressed in tons or kilograms dry weight, yield between years will be recorded on a strictly comparable basis for all localities or species.

On grazed areas two methods may be followed in adjusting for removal by grazing:

1. Estimate the herbage actually remaining on the ground and percentage utilization by weight (12). Adjustments in the forage inventory can then be made by the following formula:

$$\frac{\text{Weight herbage remaining} \times 100}{100 - \text{percentage utilization by weight}} = \text{Yield on the area if herbage was ungrazed}$$

2. Where work is extensive and it is not deemed imperative that all possible accuracy be attained, it may be desirable to reconstruct ocularly the grazed portions and estimate as on ungrazed areas. However, estimates of herbage in this fashion are not subject to absolute check. Therefore, they are less desirable than those obtained by using the first method, but they do speed up field work and lessen office compilation.

With minor species forming but a small part of the cover and approaching the lower limit of estimate, errors are apt to assume serious proportions (Table 1). This is not serious with studies whose primary purpose is the inventory of forage resources, but in a study dealing with ecological changes, such errors tend to disrupt continuous records. In view of the frequent use of material gathered in forage inventories to trace trends in plant succession, minor species that frequently fall below the lower limit of estimate should be estimated to the nearest 5 grams or the nearest gram if possible. Thus, the chance of large percentage errors lying in the choice between wide class intervals may be eliminated to some extent.

SUMMARY

A weight estimate method for use in determining grazing capacity was designed by the personnel of the Intermountain Forest and Range Experiment Station during the summer of 1936 after preliminary intensive investigative pasture and open range studies on sagebrush-wheatgrass ranges had shown wide variations to exist between grazing capacity calculated from plant cover density and that determined by grazing trials. The method was so designed that it might be substituted for density estimates in the point-observation-plot method. By the weight estimate method, productivity of species of classes is estimated on permanent or temporary plots purely randomized, or located in a gridiron or patternized arrangement. Yield and floristic composition are recorded in units of weight. Estimates can be made on plots of any size or shape.

The weight estimate method was tested in conjunction with square-foot density estimates on grass and weed types of vegetation in the Upper Snake River plains of Idaho. Under test, estimates by the weight method proved definitely superior to estimates of square-foot density in accuracy of indicating actual yield of different species or of different types of the same species.

Error of density estimates was found to lie in the relationship between density and herbage yield. As such, it cannot be readily corrected.

Weight estimates are accurate, indicative of yield, subject to actual mechanical check, rapid, and thus suited for use with replicated mechanically or randomly located plots, and the technic is easily learned with a minimum of instruction.

Range or pasture productivity as well as floristic composition are expressed in terms of grams, pounds, or tons and as such are readily understood by the average layman and are synonymous with terminology used in feedlots and feeding experiments.

Because data obtained by this method are comparable regardless of location, type of vegetation, or species, they will furnish a sound basis for stocking or management plans of any area.

Forage inventory, percentage utilization, and palatability, the three standards in range investigations, are on an identical basis affording close correlation and integration vital in estimating grazing capacity.

The weight estimate method on plots of any limited size or shape located in patternized mechanical arrangements or purely randomized may provide an excellent instrument for use in vegetative studies. It should be considered for use where records of vegetative changes, due to climate or grazing, are being maintained or where carrying capacity studies are being made.

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PARTICLE SIZE IN RELATION TO BASE EXCHANGE AND HYDRATION PROPERTIES OF PUTNAM CLAY[1]

D. M. WHITT AND L. D. BAVER[2]

NUMEROUS soil investigators have given considerable attention to the physical and chemical properties of clay. This attention has grown out of the fact that the smaller particles make up the most active portion of the soil. It has been shown by Anderson, *et al.* (1)[3] that practically all the adsorptive power of a soil, for certain substances at least, is localized in the colloidal material. Williams (24), as early as 1895, pointed out that particles less than 1.5 microns in diameter have very different properties from the larger particles.

Pfeiffer (21) showed that heat of wetting is manifested greatest by the smaller particles and that particles less than 5 microns account for the majority of the heat evolved. Giesecke (10) found hygroscopicity to be highest with the smaller-sized particles. Zunker (26) observed that shrinkage and swelling were proportional to hygroscopicity and hence the size of particles. Joseph (13) pointed out the differences in dye absorption and chemical reactivity between ultra clay and clay.

Although numerous separations of the smaller from the larger particles have been made, the effect of size within the smaller fraction upon physical and chemical properties has received relatively little study, probably because of the difficulties involved in making the mechanical separations.

Bradfield (4), working in this laboratory with a fresh sample of Putnam silt loam, separated the material remaining in suspension after 10 days into four fractions by means of the supercentrifuge. After discarding next to the largest fraction (4, pages 15, 16, 17), a few physical and chemical properties of the remaining fractions were investigated. Linear shrinkage and viscosity were greatest with the smaller fractions. Chemical analysis of the fractions did not show as wide a variation as their physical properties would indicate. The Fe_2O_3 and Al_2O_3 in the fractions below 0.1 micron were soluble, and all iron in all fractions was soluble in HCl. No appreciable difference was found in the reaction of the separates.

In the work of Gile, *et al.* (9) samples of quite a variety of soils were divided into three fractions, the "coarser fraction", consisting of particles essentially larger than 50 microns; the "fine fraction", consisting of particles between 50 and 1 micron; and the colloid, which was below 1 micron. The adsorption of dye, water, and ammonia by these three fractions was found to be greatest with the colloid and least with the "coarser fraction". Konig and Hasenbaumer (16), Ogg and Hendrick (19), and Atterberg (2) present data to show that the adsorption by different-sized particles of a soil increases with decreasing size or increasing specific surface.

Kapp (14) studied the heat of wetting on eight fractions (according to size) of 14 soils. With the exception of a Missouri soil, the heat of wetting was not manifested by particles larger than 35 microns in diameter. In all cases the calories per gram decreased with increasing particle size.

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[3]Figures in parenthesis refer to "Literature Cited", p. 915.

DeYoung (8), working with Putnam silt loam, determined the specific surface and moisture equivalent of 12 fractions below 500 microns. The separates were obtained by sieving, time sedimentation, and the use of the supercentrifuge. The specific surface and moisture equivalent increased with decreasing size.

Robinson and Holmes (22) attempted to fractionate the colloidal material by fractional precipitation, freezing and thawing, and cataphoresis. They conclude (22, page 28) that, "The attempts to separate the colloidal material into fractions of different compositions were unsuccessful and,... support the idea that separate particles of radically different composition do not exist in the suspension."

Bray (5) fractionated into three fractions the colloid (below 1 micron) extracted from various horizons of several soils from the Peorian loess region and studied their chemical differences. His data indicate that the exchange capacity of the finer fractions increases markedly with decreasing particle size. Particles smaller than 0.06 microns possessed exchange capacities from 30 to 325% larger than 1.0 to 0.1 micron particles, depending upon the nature of the colloid. Variations from 46 to 88 M. E. per 100 grams of 0.06 micron colloid were reported. By repeated fractionations and working of the colloid from the Hartsburg silt loam profile (18 to 24 inches), the exchange capacity of the 1.0 to 0.1 micron colloid was reduced from 62 to 41 M. E. per 100 grams. This was attributed to the physical breaking down of the larger colloidal particles which releases the smaller and much more surface active beidellitic material from a less active micaceous nucleus.

Brown and Byers (7) studied eight soils of widely differing origin by dividing the material below 50 microns into five fractions. The chemical analysis of the fractions was determined along with the water vapor adsorption over 3.3% and 30% H_2SO_4, and the heat of wetting. They found that the fractions of the colloids of the chernozem-like (Amarillo) and prairie (Marshall) soils show marked similarities in composition and properties within the range of colloidal size. The colloidal fractions of the podsol soil (Beckett) are characterized by marked variations in chemical composition, while the fractions of the lateritic colloids (Cecil, Durham, and Davidson) show definite differences in composition but not so marked as the podsol. They also found that, in general, the values for adsorption over 3.3% and 30% H_2SO_4 and heat of wetting decreased with increasing particle size. Differences in the properties of the same-sized fractions of different colloid were also noticed.

Marshall (18) has investigated the chemical composition and exchange capacity of bentonite, Putnam clay, and Rothamsted clay fractions, varying in size from 20 microns to less than 0.1 micron. He observed a rapid increase in exchange capacity as the particle size decreased below 2 microns.

It is the purpose of this paper to report further studies of the effect of particle size upon the colloidal properties of Putnam clay and to shed some light on the question of the stability of the respective clay fractions under drastic dispersion treatments.

EXPERIMENTAL METHODS

GRAVITATIONAL SUBSIDENCE

Two 100-gram samples of Putnam clay were dispersed by agitating for 30 minutes in an electric stirring machine. Twenty-five cc of 0.1 N NaOH were added to 25-gram samples of soil and the total volume made up to approximately

450 cc. This was the volume to which the stirring cup could be filled without loss of material.

The suspended material was washed through a 270-mesh sieve, allowing particles smaller than 53 microns to pass through. This upper limit of particle size was chosen because, as has been previously indicated, particles the size of sand do not contribute much to surface properties of soils. The material which would not pass the sieve was again stirred in the presence of the same concentration of NaOH. This procedure was repeated until additional agitation removed no more particles below 53 microns.

The particles removed from these 100 grams of soil were placed in a 6-liter bottle with parallel sides. The suspension was kept slightly alkaline to litmus throughout the separation processes. The time for particles to fall a distance of 15 cm was calculated by means of Stoke's law. The bottle was shaken thoroughly and the suspension in the upper 15 cm was siphoned off after the calculated time by air pressure applied by means of a rubber bulb. The bulb was connected through a rubber stopper which fitted the bottle. The siphoning tube was made of glass and curved upward at the bottom, the opening of which extended 15 cm below the surface of the liquid. The material settling out was re-agitated in the stirring machine once each 15 times it was redispersed.

The material less than 2 microns in diameter, the lower limit of the separations made by gravity subsidence, was first removed. Following this separation, the fractions from 2 to 5 microns and from 5 to 20 microns were removed similarly, using the calculated settling time. The time intervals with the corresponding sizes are given in Table 1. The number of times it was necessary to redisperse the material to secure complete separation is also shown.

TABLE 1.—*Time for particles to fall 15 cm.*

Diameter of particles, mm	Putnam silt loam		
	Density	Time in seconds	Number times redispersed
0.002	2.78	34,482	211
0.005	2.78	5,517	139
0.02	2.78	345	47

CENTRIFUGAL SUBSIDENCE

The centrifuge and supercentrifuge have been used for a number of years in the fractionation of soils (4, 6, 7, 12, 20, 23). Bradfield (4) made separations by the use of a celluloid sleeve which was fitted inside the supercentrifuge bowl. A spatula was used to separate the material which collected on the sleeve. Others have allowed the particles to pass through the bowl and have concentrated the suspension passing through. The latter method permits easier calculations and perhaps more reliable separations.

Ayers (3) has made a very thorough study of the problem of separation with the supercentrifuge. A brief review of his technic will be given. The supercentrifuge merely speeds up the velocity of a settling particle. The extent to which this velocity is increased is determined by two factors; first, by the number of times the force of gravity (f_0) is increased, and second, by a concentration factor (k_1). The value k_1 is expressed as parts per hundred by weight of suspended material in the suspension. In other words, if the concentration of the suspension is 1%,

the value k_1 is equal to 1.0 (not 0.01). It must be introduced because it enters into the calculation of both the centrifugal force on all of the particles at any point, and the osmotic pressure exerted by these particles at the same point. Ayers points out that the only considerable force opposing gravity in such a separation is the osmotic pressure. This must be subtracted from the centrifugal force to give the actual or resultant force on the particles.

The approximate equation for velocity given by him is

$$V = \frac{2\ r^2 k_1 f_0 g(d_1-d_2)}{9N} \tag{1}$$

where,

V = velocity of particles toward periphery of the bowl (cm/sec); r = radius of particles (cm); k_1 = parts per hundred of suspended material; f_0 = factor multiplying gravity; g = acceleration due to gravity (cm/sec^2); d_1 = density of particles (gm/cm^3); d_2 = density of medium (gm/cm^3); and N = viscosity of suspension (poises).

It should be borne in mind that this equation is only approximate, but it is believed to be as accurate as Stoke's law when applied to gravity subsidence. It is also known that very few, if any, soil particles are spherical in shape, an assumption of the law. The absolute equation is more complex and considerably more laborious to use.

The equation for velocity can be transformed into an equation for time, that is, the time necessary for particles of a definite size to "settle out", or, in other words, travel to the periphery of the bowl. Particles below this size will pass out of the bowl at the upper outlets.

There is a cylinder of space in the center of the bowl when the centrifuge is in operation. The diameter of this cylinder is equal to that of the circle of openings in the top of the separator bowl. The depth of liquid or horizontal distance a particle must travel after entering the bowl before it can be considered "settled" is equal to the radius of the bowl minus the radius of the cylinder of space. The time for a complete refillment of the liquid in the bowl can be calculated as follows:

$$\text{Time} = \frac{9N\ S'}{2\ r^2 k_1 f_0\ g(d_1-d_2)} \tag{2}$$

Where S = depth of liquid in bowl.

In equations 1 and 2

$$f_0 g \text{ (centrifugal force)} = \frac{v^2 \text{ (linear velocity)}}{r \text{ (radius of bowl)}} \tag{3}$$

Where v = $r\omega$ (angular velocity).

For accurate separations, the value k_1 must be determined prior to each time the material is passed through the supercentrifuge. If the concentration of the suspension is kept below 0.4%, the viscosity does not change sufficiently to merit its redetermination. It can be seen that the value 0.009212, the absolute viscosity of the 0.4% suspension in separation for Putnam, is not far from that of water at 26° C.

The material collecting on the celluloid sleeve was redispersed, using water made slightly alkaline with NaOH, and recentrifuged. This procedure was repeated until a determination showed less than 1 part of material in 5,000 passing through. Table 2 shows these values and the number of times it was necessary to centrifuge the material.

TABLE 2.—*Particle size and number of times of recentrifuging Putnam silt loam.*

Size of particles	Putnam silt loam	
	Parts in 5,000	Number times recentrifuged
.05 microns	1	6
.05–.10 microns	0.625	9
.10–.50 microns	0.5	26

The suspension passing through the centrifuge was concentrated by evaporation on a hot plate in large evaporating dishes. The material was never allowed to evaporate to complete dryness.

BASE EXCHANGE CAPACITY OF SEPARATES

The hydrogen systems, prepared by leaching with HCl, were used in determining the total base exchange capacity. Part of each fraction was dehydrated at 110° C and the effect of dehydration on total base exchange studied in connection with the effect of particle size.

To not less than 0.5 gram samples of each fraction, 50 cc of a 1 normal neutral $BaCl_2$ solution were added. The mixture was shaken on a reciprocating shaker for one-half hour, allowed to stand overnight, and centrifuged until clear. The supernatant liquid was siphoned off and the replaced hydrogen titrated with standard N/10 NaOH. This procedure, with the exception of allowing the mixture to stand overnight, was repeated until the number of cc of NaOH required to neutralize the resultant liquid was constant. The number of times it was necessary to repeat this operation decreased with increasing particle size, the major portion of the exchangeable hydrogen being released during the first treatment with $BaCl_2$. The results of these determinations are given in Table 3 and are shown graphically in Fig. 1 A.

When the M. E. of exchangeable hydrogen per 100 grams are plotted as a function of the average diameters of the particles the exchange capacity increases with decreasing particle size. This increase in exchange capacity is usually considered as being due to an increase in the surface per gram and hence to a greater number of "exchange points" per unit weight of material. If the exchange capacity is plotted as a function of the calculated surface, however, (Fig. 1 B), it is seen that the rate of increase in exchangeable hydrogen decreases markedly as the particle size falls below the 0.5 to 0.1 micron range, that is, as the calculated surface increases above about 75,000 sq. cm. per gram. This signifies that the total calculated surface (assuming spherical particles) increases much more rapidly than the exchange capacity as particle size decreases.

In order to have a clearer concept of the causes for differences in the exchange capacity of colloidal clays in relation to particle size and surface, it is necessary to consider briefly the existing knowledge concerning the crystal lattice make up of clay minerals. Hofmann, Endell, and Wilm (11) have shown by means of refined X-ray analyses that base exchange clays are built up on the plan of a layer lattice.

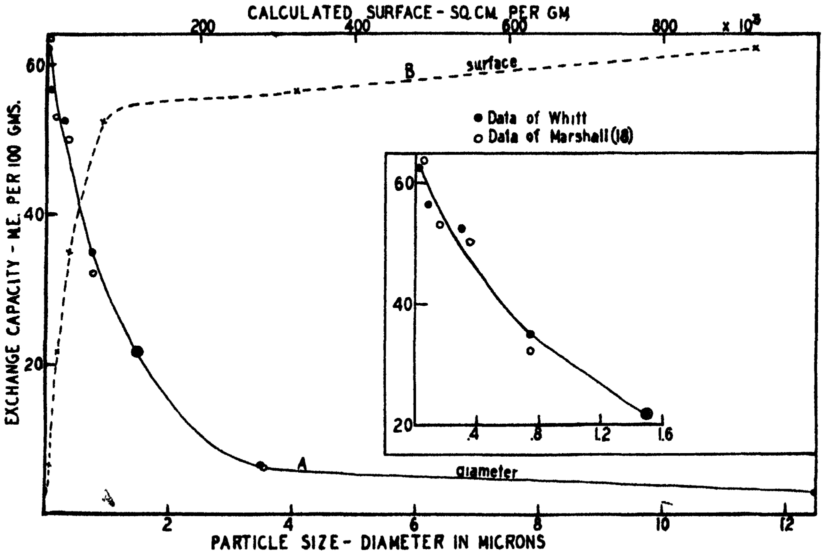

FIG. 1.—The relation of particle size and surface to the exchange capacity of Putnam clay.

In the case of montmorillonite and beidellite, two recognized clay minerals having rather high exchange capacities, the spaces between complete layer units are comparatively large. The width of these spaces varies with the water content to produce the effect of an expanding or contracting lattice as water is taken up or released by the colloid.

TABLE 3.—*Exchange capacity of various separates from Putnam clay.*

Particle size, microns	Calculated cm^2 per gram	Exchange capacity, M. E. per 100 grams	
		Whitt and Baver	Marshall (18)
20–5	1,798	2.9	——
5–2	6,189	6.6	6.3
2–1	16,064	21.7	21.7
1-0.5	30,200	35.0*	32.1
0.5–0.2	74,074	52.5	50.1
0.2–0.1			53.1
0.1–0.05	323,887	56.5	63.5
<0.05	919,540	62.2	

*Interpolated from graph.

Marshall (18), as a result of petrographic studies, has pointed out that the majority of the exchangeable cations are associated with the water molecules in the spaces that hold the adjacent layers of the crystal lattice together. He has further shown that colloidal Putnam clay is predominantly beidellite. This has been confirmed by X-ray studies on the same clay by Hofmann, Endell, and Wilm (11).

In light of these investigations it is obvious that the total effective surface contributing to base exchange in clays can not be calculated from the size of the particle unless the number of layers for each size is known. This is especially true of the larger particles. If the smaller clay particles would be formed entirely by a breakdown of the larger parallel to the layers in the crystal lattice, there should be no increase in the exchange capacity with decreasing particle size and increasing external surface. If a shearing across the sheets in the crystal lattice also took place, there should be a slight increase in exchange capacity due to the broken bonds on the edge of the different layers. If the curves in Fig. 1 are closely analyzed, it is seen that the rate of increase of exchange capacity, with decreasing particle size, mounts rapidly below the 5 to 2 micron range. If calculated on the basis of surface, the rate of increase of exchange capacity with increasing surface decreases almost abruptly when the particle size falls below 0.1 micron.

It is quite worthwhile to note that the exchange capacity of the various fractions separated from the Putnam clay by means of the supercentrifuge agree almost identically with those separated by Marshall (17) directly by using the laboratory centrifuge and fractionating through solutions of higher density and viscosity than water. Chemical and petrographic data of Marshall indicate that the fractions smaller than 0.5 micron are composed of homogeneous material of the beidellite type. The 0.5 to 0.2 micron fraction has a relatively high phosphorus content; the 0.2 to 0.1 micron fraction contains the highest amount of alumina. The presence of unidentified minerals in the fractions from 2 to 0.5 microns was indicated. A large percentage of this material was free quartz and cristabolite.

Bray (5) attributes the regular increase in base exchange capacity with the decrease in particle size to a variation in the minerals which make up the colloids and accompany the size variations rather than to the decreased particle size itself. This concept would conform to the results obtained in this study. Unquestionably, there is the possibility that the larger particles may not only be different in their mineral composition, but also may contain small amounts of finer and much more active material cemented to their surfaces which even rather drastic dispersion methods do not remove. Examinations under the petrographic microscope revealed that the quartz particles possessed clean surfaces. There were other mineral particles in the larger fractions, however. Bray suggests that the beidellitic material can only be removed from the surfaces of the micaceous nucleus by repeated triturations. His concept of physical weathering would conform to these data which show high base exchange properties per unit surface of the large fractions, since the beidellitic material would not

significantly enter into the calculations of surface but would be dominant in contributing to base exchange.

Kelley and Jenny (15) have ground various colloids and produced exceptional increases in their exchange capacities. These large increases have been attributed to decreasing particle size and to increasing the amount of surface exposed for base exchange reactions. There is considerable doubt, however, whether the ground colloid has the same mineralogical properties as it possessed prior to grinding. Grinding may have changed the nature of the mineral more significantly than the properties dependent upon size.

SORPTION OF LIQUIDS AND SWELLING OF SEPARATES

The amount of water and toluene adsorbed by each fraction was determined by the use of the apparatus described by Winterkorn and Baver (25). Readings were taken at 1-, 5-, 10-, and 30-minute intervals, followed by readings every hour. Observations were recorded until the amount of adsorption was less than 0.05 cc per hour. The results are given in Table 4 and shown graphically in Fig. 2.

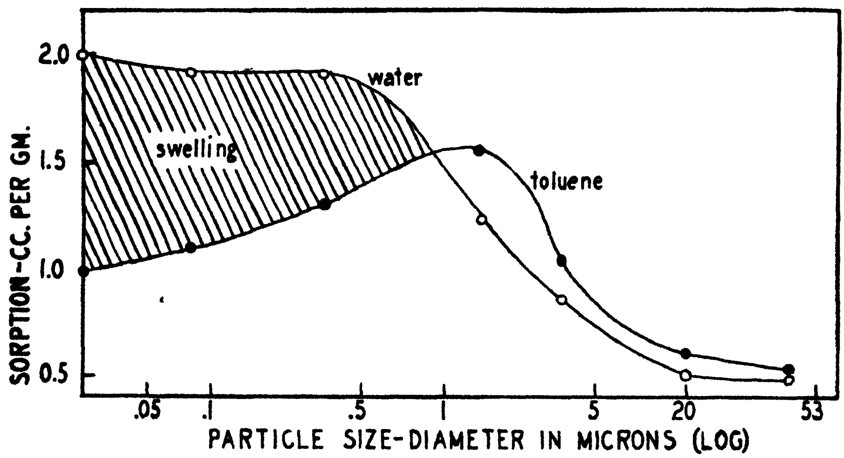

FIG. 2.—Sorption of liquids and swelling of Putnam clay as a function of particle size.

TABLE 4.—*Hydration of various separates from Putnam clay.*

Particle size, microns	Calculated surface cm^2 per gram	Sorption of liquids			Moisture equivalent (8) cc/gm
		Water cc/gm	Toluene cc/gm	Swelling cc/gm	
20–5	1,798	0.499	0.593	−0.094	0.327
5–2	6,189	0.830	1.009	−0.179	0.609
2–1	16,064	1.197	1.518	−0.321	0.798
1–0.5	30,200	1.62	1.47	+0.150	0.777
0.5–0.1	74,074	1.876	1.272	+0.604	0.904
0.1–0.5	323,887	1.874	1.067	+0.807	1.86
<0.05	919,540	1.956	0.976	+0.980	——

Toluene sorption rises to a maximum with particles that are slightly larger than 1 micron. This is probably due to the fact that as the size of particles increases the size of the pores increases, thereby allowing the large toluene molecules to enter and more nearly fill the total pore space. Beyond the 1-micron point the decrease is most likely due to the decreasing pore space per gram, especially the larger pores.

The adsorption of water is fairly constant in particles smaller than 0.5 micron in diameter. The curve gradually decreases beyond this point with increasing particle size. We would expect the adsorption of water to be greatest with the smaller fractions, due to the increased surface and pore space available.

In the work of Winterkorn and Baver (25), the difference between the intake of water and a non-polar liquid is taken as a measure of swelling. The results obtained in this study show that there is very little, if any, swelling of particles separated from Putnam clay that are larger than 1 micron in diameter. Since only one soil has been investigated, this relationship should not be applied to all soils until more facts are obtained.

The relation of water sorption to the calculated surface is shown in Fig. 3. The moisture equivalent data of DeYoung (8) are also includ-

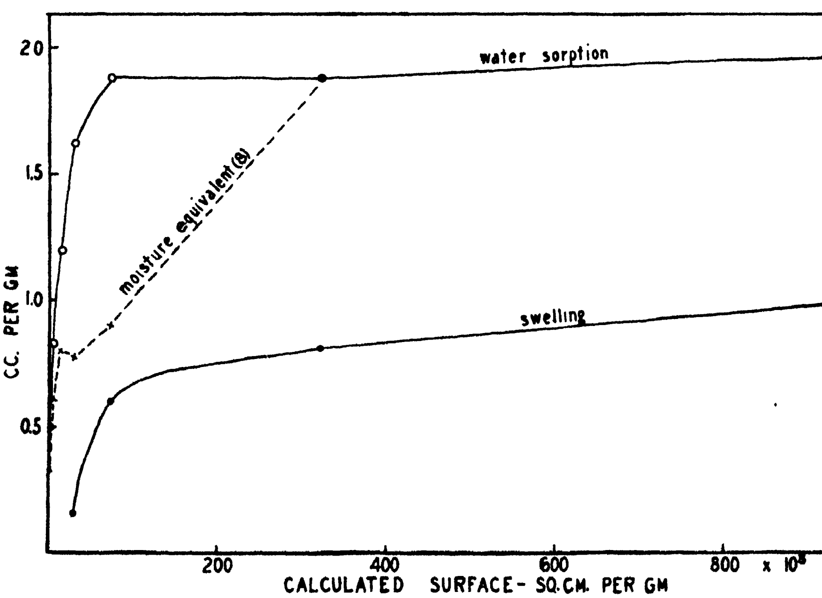

FIG. 3.—The relation of surface to the hydration of Putnam clay.

ed. When sorption of water and swelling are plotted as a function of surface, it is seen that the rate of increase of the hydration curve drops off markedly below the 0.5 to 0.1 micron size range. This curve is similar to that for exchangeable hydrogen in Fig. 1. Since the forces responsible for attracting and holding water molecules to the surface are probably the same that take place in base exchange phenomena, one should expect these curves to be more or less alike. It is shown in

Fig. 4 that the sorption of water by Putnam colloid is a direct function of the exchange capacity of the particles. Hydration, therefore, should not be considered entirely from the point of view of the total surface exposed, but should be analyzed in light of the active points on the surface.

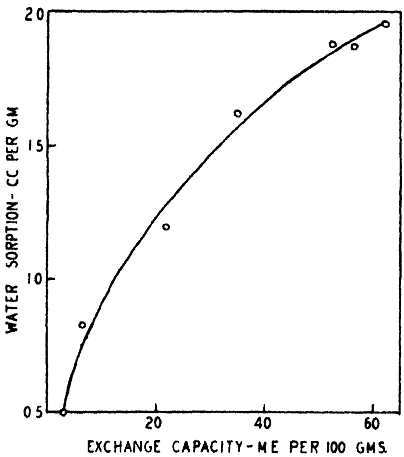

Fig. 4.—The sorption of water by Putnam clay in relation to exchange capacity.

The sorption of water with the larger-sized fractions is largely a matter of filling the pore space. The maximum is quickly reached in the large fractions and remains constant. This tendency gradually decreases as the particles become smaller. The slower capillary rise of water in the smaller pores and the fact that swelling itself is a slow process combine to give a slow rate of water sorption with the smaller-sized particles. The lower amount of swelling and the increasing size of pores in the case of the larger particles, suggests that the sorption process consists of forming a film on each particle and filling the pores.

The moisture equivalent results of DeYoung indicate that the amount of water which the various separates will hold against a force 1,000 times that of gravity increases rapidly with the calculated surface until the 2-micron particle size is reached. From this point the curve becomes less steep. It is interesting to note that the swelling forces are so pronounced with particles smaller than 0 1 micron that a centrifugal force of 1,000 times gravity does not decrease the moisture content appreciably below that which the colloidal material will take up when brought into contact with a capillary column of water. At this point the moisture equivalent values are the same as those for sorption.

CONCLUSIONS

Observations made during the separating processes led to the conclusion that particles the size of those separated in this study are stable under rather drastic dispersion treatments. Whether primary particles alone were obtained cannot be definitely determined without further investigation. It is believed, however, that the repeated stirring and peptization of the various separates destroyed the major portion of the aggregates, and that any aggregates present after dispersion were nearly as stable as the primary particles.

This does not confirm the work of Joseph (13) and DeYoung (8). It is possible in the case of DeYoung's investigations that the separation process was not continued long enough; for example, the material was resuspended a maximum of 60 times for the clay separation. In this study the 2-micron fraction was resuspended 211 times.

Moreover, it is possible that the factor k_1 appearing in equation 1 was not taken into account, which would explain how the whole sample would eventually pass through the supercentrifuge. It can be seen in equation 1 that the velocity of a particle travelling toward the periphery of the bowl varies directly with k_1. As the amount of material left in suspension decreased, velocity of the particles would decrease. With the same speed of refillment and a continually decreasing velocity of subsidence of the particles, larger and larger particles would be carried out of the bowl until the sample was exhausted.

There is also the possibility of smaller particles being cemented to the larger ones. This material may be gradually removed as redispersion continues, but this study indicates that stable primary particles or stable aggregates are obtained if the process is continued long enough.

There are many precautions to observe in effecting exact size separations with the supercentrifuge. The exact speed and volume of the bowl must be known. The radius of the cylinder of space in the bowl must be determined in order to know the exact depth of liquid to use in equation 2. The speed of the bowl cannot be decreased too greatly or excessive leakage at the bottom of the bowl will result.

Many sizes have been suggested for the upper limit of colloidal size in soils. Most of these limits have been set up arbitrarily, while others have been based on experimental data. The results of the study with Putnam clay indicate clearly that the particles below 1 micron possess very different properties from the particles above this size. The fraction between 1 and 0.5 micron was almost entirely absent in this soil, but by interpolation its properties can be obtained.

The property of swelling (Fig. 2) is not present in particles greater than 1 micron and the maximum toluene adsorption takes place in the same particle size range. The wide break in exchange capacity is also very near this point. (Fig. 1).

If the upper limit of colloidal size is taken, first, as that point below which physical and chemical properties are very nearly the same, and second, where a distinct break occurs in the curve showing the different properties of the clay as a function of particle size, then, on the basis of the few properties determined in this investigation, 1 micron is not far from the upper limit of colloidal size in the Putnam silt loam. Additional study is needed before the full importance of particle size is realized.

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VARIATION IN SOILS WITH RESPECT TO THE DISPOSITION OF NATURAL PRECIPITATION[1]

R. S. STAUFFER AND R. S. SMITH[2]

DURING recent years, when much attention has been given to the problems of soil conservation, it has become increasingly apparent that more information regarding the properties of soils is needed than is now available. As has been pointed out (2)[3], the infiltration capacity of soils is one of the properties about which more information is needed upon which to build erosion control practices.

The infiltration capacity of soils is a complex property which varies not only between different soils, but also in the same soil with changing conditions within the soil. The securing of this type of information which is applicable to widely scattered soils with different physical properties is attended by many difficulties. Probably the method in which the erosion type lysimeter (2) is used comes as near to securing this information as any method yet evolved. But even this method has certain shortcomings, in addition to the limitations of rather high cost, that should be recognized. This point will receive further attention later in this paper.

A project in which the erosion type lysimeters are used was set up at the Illinois Agricultural Experiment Station at Urbana, and the results for more than 18 months are now available. It is the purpose of this paper to describe the methods used in setting up this project and to give a summary of the results. At a later time an analysis of the results and a further consideration of the factors involved in such a study will be taken up.

OBJECT AND PLAN

The primary object of this study is to determine how soils, with different physical and chemical characteristics, differ in their disposition of natural precipitation. Eight soil types, extensively developed in Illinois and possessing profiles of differing permeabilities, were sampled in triplicate in cylinders 36 inches in diameter and 40 inches long without disturbing the natural structure. The filled cylinders were installed on the University South Farm in such a manner that the precipitation falling on them can escape by runoff, percolation, or evaporation. The runoff and percolate are caught and measured separately and, therefore, since the soils are kept fallow, it is possible to determine the amounts of water lost from each cylinder in the different ways. This makes it possible to compare the soils with respect to what becomes of the water falling on them.

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[1]Contribution from the Division of Soil Physics, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication August 17, 1937.

[2]Associate in Soil Physics and Chief in Soil Physics and Soil Survey, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 923.

EQUIPMENT

The equipment for securing the samples was similar to that described by Musgrave (3), but there were several differences which probably should be mentioned. The cylinders used in this work are 40 inches long instead of 36 inches. This additional length seemed desirable and in our work was necessary so the cylinder would reach through the B horizon in some cases. The cylinders were forced down into the soil in very much the same manner as was done by Musgrave, but after the desired depth was reached and before the cylinders were lifted from the excavation, it was found necessary to devise some way to avoid slipping of the soil column in the cylinder during hoisting. This was done by continuing the excavation around the outside of the cylinder to about 18 inches below the bottom of the cylinder. Then six lugs of galvanized scrap iron 3/16 by 1½ inches, made in the shape of an L with ¾-inch vertical by 1-inch horizontal measurements, were equally spaced around the inside of the bottom of the cylinder. These were held in place by 3/16-inch galvanized iron screw-eye bolts, passing through holes near the bottom of the cylinder and threaded into the lug. In addition, when cutting off the soil column smoothly and flush with the bottom of the cylinder, as soon as enough space was cleared two 2 by 6 inch pieces of plank were fastened securely to the bottom of the cylinder. This was done by using ⅜-inch steel rods, which passed through holes in the pieces of plank and hooked over the top of the cylinder. These rods were tightened by means of turnbuckles (Fig. 1).

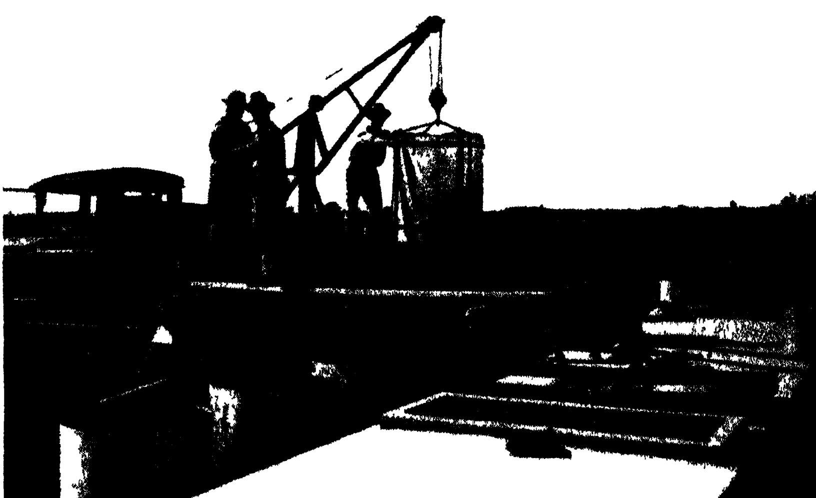

FIG. 1.—Equipment for handling cylinders of soil.

Before the empty cylinders were placed on the truck to be taken to the field two reinforcing bands of mild steel ¼ by 1 inch were placed around them and tightened by means of a bolt through lugs on the

band (Fig. 1). These bands were not removed until the cylinders of soil were placed in their final position beside the drainage cellar. The reinforcing bands were then removed and placed on empty cylinders to be used for the next set of samples. In addition to the light bands, two heavier bands 3/8 by 1 1/2 inches, were placed around the cylinders before forcing them into the soil. One of these bands was placed just flush with the top of the cylinder and the other from 1 1/2 to 2 1/2 inches from the bottom so as to permit the edge of the cylinder to be the cutting edge. The position of this latter band was governed by the toughness of the soil being sampled; the tougher the soil, the closer the band was placed to the bottom of the cylinder.

The hoist for loading and unloading the cylinders of soil was mounted permanently on a truck (Fig. 1). This was desirable, since so many samples were collected and also since some of the samples were secured as much as 150 miles from the University. It was necessary to block up the body of the truck while loading or unloading the cylinders of soil. During transit the crane was removed from the vertical shaft of the hoist. This required only a few minutes.

When the cylinders of soil were brought to the University they were set in pans of crushed quartz and sealed tight around the outside, as was done by Musgrave (2). Containers were placed in the drainage cellar and connections were completed to catch the runoff and the percolate. The excavation around the cellar was filled with soil nearly to the top of the cylinders and seeded to grass (Fig. 2).

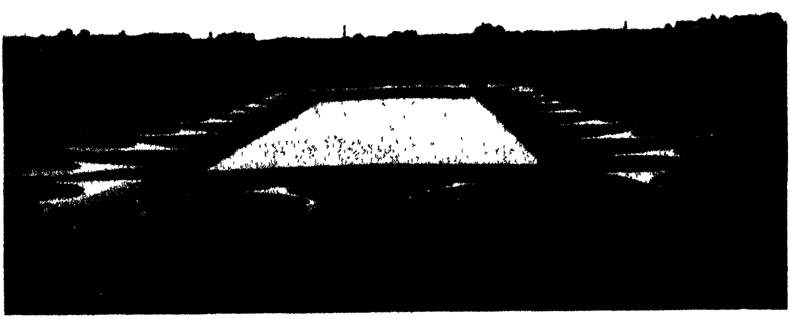

FIG. 2.—Arrangement of cylinders of soil and top of drainage cellar.

A standard Weather Bureau rain gauge was installed 15 feet from the drainage cellar. The top of the rain gauge is the same distance above the surface of the ground as are the tops of the cylinders of soil.

HOW THE SOILS WERE HANDLED

During the week of June 4, 1935, the soils in all the cylinders were spaded to a depth of 6 inches. Each spadeful was removed from the cylinder and inverted so the sod would be turned under when the soil was replaced in the cylinder. In returning the soil to the cylinders

care was taken not to leave any large air spaces in the soil. The surfaces of the soil in the cylinders were then smoothed off, no attempt being made to maintain the original slope of the soils. In all cylinders the surface of the soil was ½ inch higher at the back of the cylinder than at the surface outlet, thus providing a slope of approximately 1.4%. This slope has been maintained as nearly as possible. The surface of the soil is kept slightly higher than the surface outlet. As soil is removed by surface runoff it is replaced by surface soil of the particular type involved. On June 11, 1935, the first measurements were made and they have been continued since. The percolate is measured daily and the runoff whenever there is any runoff.

DESCRIPTION OF THE SOILS

Eight prairie soil types were sampled in triplicate. Four of these, Tama silt loam, Muscatine silt loam, Edina silt loam, and Putnam silt loam, have been described in soil survey publications of the Bureau of Chemistry and Soils. The other four, Osceola silt loam, La Rose silt loam, Elliott silt loam, and Cisne silt loam, will be described briefly here.

The descriptive name for Osceola silt loam is brown-gray silt loam on clay over outwash. It occurs on nearly level to gently undulating topography on glacial outwash plains. There is usually enough slope for moderate surface drainage, but the subsurface drainage is slow. The structure particles in the A_1 horizon are small and easily destroyed, so that the surface has a tendency to puddle. In the B horizon the color of the structure particles is drabbish-gray or gray. When the structure particles are broken down by rubbing, the color of the mass is brownish-yellow. The characteristics of the profile indicate that it was developed in the presence of a high water table. This type occurs extensively in the northern two-thirds of Illinois.

La Rose is a light brown silt loam on calcareous drift. It may be thought of as a light or eroded phase of Clarion silt loam. It occurs on rolling topography and is subject to serious erosion. On the flat uplands in the area where the La Rose samples were secured, there is a thin covering of loess, but where these samples were taken this loess cover has been removed, exposing the glacial till of Wisconsin age. In the surface soil the structure particles, which are small, are easily destroyed and water is not as readily absorbed as might be expected from the mechanical composition of the soil. The soil profile indicates that it was developed under good drainage conditions.

Elliott silt loam is described as brown silt loam on compact, medium plastic, calcareous till. It occurs on Wisconsin till where the topography is undulating to gently rolling. The surface drainage is good, but the subsurface drainage is slow. The structure of the A_1 horizon is granular and in the samples used in this work the structure particles are very stable. The surface remains friable and pulverulent even after heavy rains. Therefore, this soil is very absorbent and having a surface horizon about 10 inches thick, can absorb and hold a large quantity of water. While the A_1 horizon is a dark brown color, the rest of the profile has a drabbish or grayish cast, indicating that this soil was developed under rather poor drainage conditions.

Cisne silt loam is probably very similar to Cory silt loam as recognized by the Bureau of Chemistry and Soils. It is described as a gray silt loam on "tight" clay. The surface soil seems to be very little granulated, but is largely single-grained

structure and compacts readily. This soil occurs on the nearly level-lying areas in the southern third of the state. It is a poorly drained soil, not only because of the nearly level topography where it occurs, but also because of the relatively impervious B horizon and underlying Illinoian gumbotil.

RESULTS

Measurements of the runoff and percolate have been made since June 11, 1935, and therefore up to December 31, 1936, a period of approximately 18½ months has been covered. The results in Table 1 are given for the whole period and also for the 6½ months of 1935 and the entire year of 1936 separately. This is done because the soils were spaded at the beginning of the study, which would undoubtedly have some influence on the results for some time after spading. The precipitation for the year 1935, from June 11, was 19.99 inches and for the entire year of 1936, 35.81 inches. For the whole period under consideration the precipitation was, therefore, 55.80 inches.

TABLE 1.—*Runoff and percolate from samples of eight Illinois soil types.**

	Osceola	Tama	Muscatine	Edina	La Rose	Elliott	Putnam	Cisne
			June 11, 1935, to Dec. 31, 1936					
Runoff	29.3	18.0	18.2	19.6	26.8	19.6	28.5	21.1
Percolate	4.1	21.4	27.8	20.3	12.9	18.3	3.3	4.4
			June 11, 1935, to Dec. 31, 1935					
Runoff	21.5	8.6	9.4	10.4	19.6	7.8	14.0	14.5
Percolate	7.5	31.6	37.9	30.6	22.9	27.8	7.0	4.3
			Jan. 1, 1936, to Dec. 31, 1936					
Runoff	33.7	23.3	23.2	25.0	31.2	26.1	36.6	24.8
Percolate	2.2	15.7	22.2	14.5	7.3	13.0	1.1	4.4

*Averages of triplicates, expressed as percentages of total precipitation.

DISCUSSION AND CONCLUSIONS

As the results in Table 1 show, the soils included in this study vary markedly from each other with respect to their disposition of the natural precipitation. During the entire period for which results are available, the runoff ranged from 10.0 inches from Tama to 16.3 inches from Osceola. The percolate ranged from 1.8 inches from Putnam to 15.4 inches from Muscatine.

As mentioned previously, in this method of study the conditions under which the soils are functioning are not entirely natural and, therefore, the interpretation of the data is less simple than might appear upon first thought. One factor which would undoubtedly have considerable influence upon the movement of water through the soil profile under natural conditions is the permeability of the material underlying the 40-inch column of soil. If this material is readily permeable, it would seem that the results secured by the erosion type lysimeter would more nearly approach those occurring under natural

conditions than if this underlying material is slowly permeable. Therefore, it appears that with the erosion type lysimeter natural conditions are more nearly approached with some soils than with others.

Two soils, Muscatine silt loam and Cisne silt loam, which illustrate the conditions referred to, are described in Fig. 3. Muscatine silt loam is permeable throughout the profile and, where the samples were secured, to a depth of 20 feet where the loess from which it is derived rests on Illinoian till. Since the soil and the soil material from which it is derived are readily permeable to so great a depth, it seems unlikely that providing ready drainage at a depth of 40 inches would materially accelerate the percolation of water through the soil profile. Cisne silt loam, on the other hand, has a well-developed claypan subsoil and is underlain at a depth of 5 feet or less by Illinoian gumbotil. It seems, therefore, that with this soil the introduction of ready underdrainage at a depth of 40 inches may materially increase the total percolation since the percolation through the upper 40 inches, while slow in any case because of the claypan subsoil, is probably further retarded under natural conditions by the very slowly permeable gumbotil which is present so near the surface. The saturated condition which exists between the claypan of the soil profile and the gumbotil substratum would not be present in the lysimeter setup. The retarding effect on percolation of the gumbotil would thus not be present in the lysimeter columns and, therefore, the total percolation would probably exceed that under field conditions.

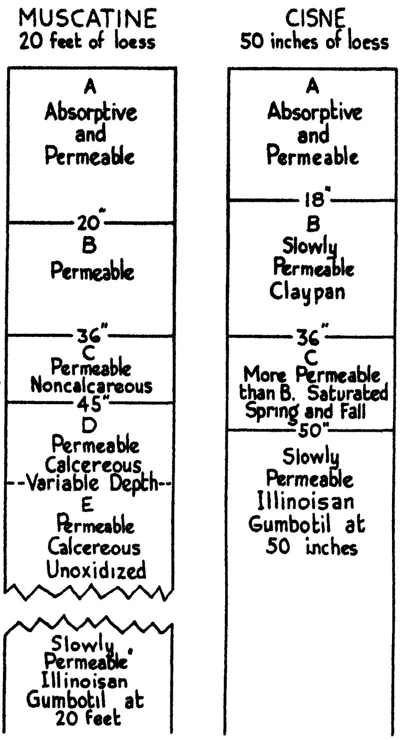

FIG. 3.—Certain profile features of Muscatine silt loam and Cisne silt loam.

Provision has been made for supplementing the work reported in this paper by a study in which the Russian type lysimeter (1) is to be used. It would appear that this type of lysimeter is admirably adapted to measure the percolate from undisturbed soils which have no slowly permeable horizon in the profile. But, as has been pointed out by Joffe (1), with a soil having a slowly permeable horizon in the profile, horizontal movement of water may take place along this horizon. Such movement would undoubtedly be accelerated by placing a lysimeter at the surface of the slowly permeable horizon. Therefore, for this kind of study, the Russian type lysimeter, in addition to being subject to

the same type of difficulties as the erosion type lysimeter, is subject to the added difficulty of horizontal movement of water. It seems, therefore, that the Russian type lysimeter may be unsuitable for getting at percolation rates in some soils.

As mentioned above, the soil columns included in this study are not under entirely natural conditions and the claypan profiles depart further from the ideal than do those which are permeable throughout. Yet for securing information on numerous soil types this method approaches the ideal as closely as any yet devised.

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THE FORAGE COVER IN HEAVILY GRAZED FARM WOODS OF NORTHERN INDIANA[1]

OLIVER D. DILLER[2]

LAND planning reports of many of the Corn Belt states recommend an extensive shift from excess areas of grain crops toward greater production of hay and more acreage in permanent pastures. These recommendations have focused increased attention on the millions of acres of pasture land in the Corn Belt which, to use Secretary Wallace's words, "are producing only one-third to one-half as much as they might in terms of milk and beef" (10).[3] The Soil Conservation and Domestic Allotment Act of 1936 is encouraging this general shift toward hay and pasture and agronomists have recently made noteworthy contributions on the establishment and management of productive pastures.

These studies, however, have not covered to any great extent the problems of woodland pasture which in the Corn Belt comprises practically one-third of all the pasture land east of the prairies. While recorded in the Census as "Woodland Pasture", these areas vary widely in their character and carrying capacity. Most of these woodland pastures have been so seriously injured by continuous overgrazing as to be inadequate for the satisfactory maintenance of livestock and ruined for sustained timber production (2). Agronomists recognize the poor quality of such pasture and in the better agricultural sections discourage the practice of grazing the woods. It is unfortunate that with the acknowledged need for more productive grazing lands there has been no critical study of woodland pastures with the object of improving the carrying capacities of the better areas and determining the best land use for such areas as are definitely submarginal for forest production.

In land use projects too frequently the error is made of assuming that lands which are marginal or submarginal for agriculture or forage production are *ipso facto* forest or potential forest land. Fully 50% of the pastured woodlands have been so seriously injured by continuous overgrazing that they are no longer capable of yielding forest crops and are definitely submarginal for profitable forest production as well as for pasture. Since one of the first principles of good farm management is to obtain good crop yields from each unit of land, it is obvious that these unproductive pastured woodlands present an important problem in land use which requires additional study by both foresters and agronomists.

As a phase of the problem of managing farm woodlands for the continuous production of forest crops, certain aspects of woodland grazing have been under investigation for a number of years at the Central States Forest Experiment Station in cooperation with the Departments of Forestry and Animal Husbandry of Purdue University Agri-

[1]Contribution from the Forest Service, U. S. Dept. of Agriculture. Received for publication August 27, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 933.

cultural Experiment Station. These studies have definitely established the incompatability of grazing and timber production under present grazing practices in the Corn Belt (1, 2). The purpose of the present study has been to determine the general trend of succession of the vegetative cover in heavily grazed woodlands and its relation to the possibilities of such areas to regenerate naturally with desirable timber species.

METHODS

During the summers of 1931 and 1932, 70 half-acre permanent sample plots were established in grazed woodlands distributed over 14 counties in northern Indiana. All trees in the overhead stand on these plots were tagged, located, and tabulated according to their diameter, height, and crown class. Tree reproduction and the vegetative ground cover were recorded on eight mil-acre quadrats uniformly distributed over each plot and have been measured annually since then.

The method of making the inventory of plant cover was similar in principle to that recently described by Stewart and Hutchings (9). The data were taken in terms of square links in the mil-acre quadrats having an area of 100 square links. This gave the coverage values directly in terms of percentages. The basis for the segregation of indicator plants used in the frequency and coverage tables was to accept only those species which occurred in at least half of the woodlands studied. Although these studies on the lesser vegetation were supplemented by general observations, the major part of the data was obtained from the seedling reproduction quadrats. This report, therefore, does not represent an exhaustive survey of indicator plants, but certain very interesting trends have nevertheless been revealed.

STAGES IN RETROGRESSION FROM UNGRAZED FOREST TO WOODED PASTURE

The ungrazed woodland in which there has not been excessive cutting is characterized by trees in all stages of development from seedlings to mature trees. The majority of the plants in the ground cover of the undisturbed forest indicate shaded conditions. Artificial interference with the local environment of such a community quickly drives out these characteristic species and the general trend, as may be seen from the accompanying tables and discussion is from mesic to xeric conditions. Day and DenUyl (1) recognize four stages of decadence of the pastured woodland. These have been arbitrarily termed the early, the transition, the open park, and the final. The early stage represents the condition which is quickly reached following the admission of cattle to the undisturbed forest. Cattle, sheep, and other livestock soon clean out all the tender herbs and grasses and then turn to the foliage of the shrubs and young trees. Within a few years all of the most palatable reproduction has been killed by repeated browsing and trampling, and the lower limbs of the older trees have been browsed back. In the transition stage the overhead stand has been opened up to such an extent that more sunlight reaches the ground. The additional light, due to the reduction of the crown canopy to less than 80%, along with the free sweep of air currents through the forest are important in the almost complete disappearance of the original ground cover, which is replaced by unpalatable weeds and scattered patches of bluegrass sod.

The last two stages, namely, the open park and final, represent woodlands in which the conditions which brought about the transition stage have continued over a longer period. As shown in Fig. 1, the crown canopy has been opened up to a greater extent, accompanied by a heavier sod formation, the invasion of weeds, more excessive packing of the soil, and the almost complete destruction of the leaf litter and mull.

Since woodlands in the early stage regenerated quickly following the removal of livestock and since it early became evident that those in the final stage were incapable of natural regeneration, this study was confined to the vegetation of the ungrazed, transition, and open park woodlands. Fig. 1 shows graphically the effect of grazing on the

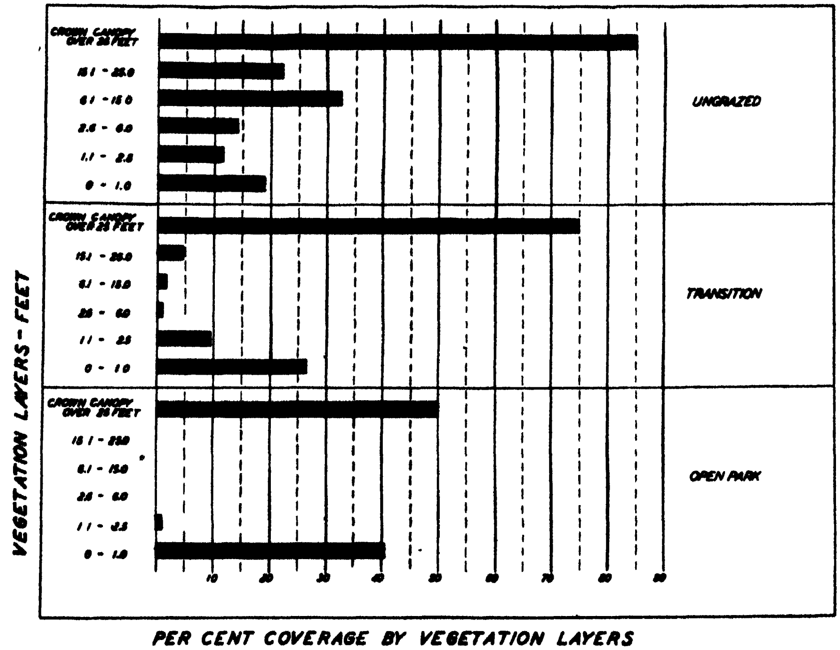

FIG. 1.—The percentage of cover by each of six vegetation layers in typical ungrazed, transition, and open park woodlands.

various vegetation layers. The percentage of cover by each of six size classes in typical ungrazed, transition, and open park areas is indicated. The rather balanced coverage of the various vegetation layers in the ungrazed woodlands is strikingly contrasted to the decreasing percentage of the intermediate layers in the transition stage and their almost complete absence in the open park stage. Also conspicuous is the fact that the vegetation layer up to 1 foot in height occupies an average coverage of only 20% in the ungrazed stage as compared to an increase to 27% in the transition and to approximately 40% in the open park.

A similar study by Lutz (6) in Pennsylvania shows this same rela-

tionship. Obviously, as the crown canopy is opened up there is an increase in the amount of herbaceous vegetation, while the size classes above the herbaceous vegetation are practically eliminated. The early effect of grazing appears to be the most severe in the lower vegetation layers. As grazing continues the effect of the elimination of the lower vegetation layers is naturally carried into the higher layers through height growth of the smaller trees.

THE GROUND COVER

It is fully realized that conclusions based on indicator plants must be made with caution because of the wide variations which occur between farm woodlands. In a general way, however, it has been possible to follow the trend of the vegetation from the ungrazed forest to the wooded pasture. The replacement of one type of plant cover by another is gradual, yet definite, as indicated in Tables 1 and 2. These tables show in which condition the maximum frequency and coverage of certain plants commonly found in these woodlands occur.

THE UNGRAZED CONDITION

The ground cover in the ungrazed farm woods in which there has not been excessive cutting is characterized by certain species which indicate mesic conditions. In Table 1, Virginia creeper is shown to be the most common plant in the ground floor of ungrazed oak-hickory woodlands occurring in 62% of the quadrats and having an average coverage of 6.8%. Other plants which were found in the ungrazed quadrats are asters, sedges, white snakeroot, black snakeroot, shining bedstraw, poison ivy, false spikenard, violets, and wild licorice. A total of 86 species were noted in the quadrats, but, as shown in Table 1, only 20 qualified through frequency of occurrence for consideration as characteristic plants. It is true that a number of these, such as cinquefoil, sedges, asters, violets, and shining bedstraw, are found in all three conditions, indicating that they are capable of withstanding the wide contrast in environmental conditions of the closed forest and wooded pasture. The probable reason for their presence under all of the above conditions is that they are both hardy and unpalatable.

In the beech-maple type it is much more difficult to segregate the indicator plants because of the overlapping of species from one condition to another. However, by studying the relative frequency and coverage figures of the various species, a trend similar to that found in the oak-hickory type becomes evident. With but few exceptions, the indicator plants found in the beech-maple type include those of the oak-hickory; but there are a number of additional species, such as, white-bear sedge, pokeweed, cleavers, nodding fescue, blackberry, and wild lettuce. From a total of 52 species found in the ungrazed condition, 22 were present in at least half of the plots; in the transition, 24 out of 53; and in the open park, 16 out of 41. These figures indicate the wide variations in ground cover which exist between woodlands.

Some of the plants which occurred to a more limited extent in ungrazed woodlands of both the oak-hickory and beech-maple types are

TABLE 1.—*Coverage and frequency, in percentage, by important species and groups in ungrazed, transition, and open-park woodlands in northern Indiana, oak-hickory type.*

Scientific name	Common name	Ungrazed*		Transition†		Open-park‡	
		Frequency %	Coverage %	Frequency %	Coverage %	Frequency %	Coverage %
Parthenocissus quinquefolia (L) Planch	Virginia creeper	62	6.8	—	—	—	—
Smilacina racemosa L	False spikenard	21	1.4	—	—	—	—
Sanicula canadensis L	Black snakeroot	13	0.4	—	—	—	—
Galium circaezans Michx	Wild licorice	12	0.2	—	—	—	—
Smilax herbacea L	Carrion flower	11	0.2	—	—	—	—
Cystopteris fragilis L	Bladder fern	9	1.4	—	—	—	—
Podophyllum peltatum L	May apple	9	0.4	—	—	—	—
Desmodium canadense (L) DC	Canadian tick-trefoil	5	0.2	—	—	—	—
Desmodium acuminatum (Michx) DC	Pointed-leaved-trefoil	6	0.1	—	—	—	—
Ribes cynosbati L	Prickly gooseberry	5	0.2	—	—	—	—
Rhus toxicodendron L	Poison ivy	26	1.8	—	—	—	—
Eupatorium urticaefolium Reichard	White snakeroot	48	1.0	15	0.9	—	—
Circaea latifolia Hill	Enchanter's nightshade	21	1.2	13	0.4	—	—
Potentilla simplex Michx	Cinquefoil	7	0.1	8	0.3	28	1.6
Geum canadense Jacq	White avens	14	0.2	7	0.2	—	—
Aster species§	Aster	52	5.2	10	0.3	14	0.2
Viola papilionacea Pursh	Common blue violet	16	0.7	27	0.4	26	0.4
Galium concinnum T & G	Shining bedstraw	24	1.0	20	3.7	47	2.8
Carex cephalophora Muhl	Oval-headed sedge	36	6.3	35	13.1	76	17.6
Impatiens biflora Walt	Spotted touch-me-not	7	1.2	39	7.3	—	—
Leersia virginica Willd	White grass	—	—	23	0.7	—	—
Arisaema triphyllum (L) Schott	Indian turnip	—	—	18	0.4	—	—
Pilea pumila var. *Deamii* (Lunell) Fernald	Clear-weed	—	—	12	0.8	—	—
Rubus occidentalis L	Black raspberry	—	—	10	0.6	—	—
Poa pratensis L	Kentucky blue-grass	—	—	38	6.3	82	17.2
Hedeoma pulegioides (L) Pers	American pennyroyal	—	—	16	0.6	19	0.2
Parietaria pennsylvanica Michx	Pennsylvania pellitory	—	—	10	0.2	9	0.4
Danthonia spicata (L) Beauv	Poverty grass	—	—	—	—	16	0.6

*Based on 6 ungrazed woodlands; 43 quadrats.
†Based on 5 transition woodlands; 44 quadrats.
‡Based on 5 open-park woodlands; 45 quadrats.
§Mostly *Aster cordifolius* L., heart-leaved aster.

TABLE 2.—*Coverage and frequency, in percentage, by important species and groups in ungrazed, transition, and open-park woodlands in northern Indiana, beech-maple type.*

Scientific name	Common name	Ungrazed*		Transition†		Open-park‡	
		Frequency %	Coverage %	Frequency %	Coverage %	Frequency %	Coverage %
Impatiens biflora Walt	Spotted touch-me-not	12	0.8	1	0.1	—	—
Circaea latifolia Hill	Enchanter's nightshade	16	1.5	22	0.6	—	—
Carex albursina Sheldon	White bear sedge	17	0.9	12	0.3	—	—
Phytolacca americana L.	Pokeweed	7	0.6	12	0.6	—	—
Pilea pumila var. *Deamii* (Lunell) Fer	Clear-weed	16	0.7	30	2.2	—	—
Viola papilionacea Pursh	Common blue violet	19	0.5	23	0.8	—	—
Galium aparine L.	Cleavers	6	0.2	19	4.3	—	—
Parietaria pennsylvanica Muhl.	Pennsylvania pellitory	6	0.2	14	0.4	—	—
Arisaema triphyllum (L) Schott	Indian turnip	12	0.2	19	0.2	—	—
Galium circaezans Michx	Wild licorice	6	0.1	3	0.1	2	0.1
Festuca obtusa Spreng	Nodding fescue	7	0.3	1	0.1	3	0.1
Eupatorium urticaefolium Reichard	White snakeroot	24	1.3	16	1.6	3	0.1
Parthenocissus quinquefolia (L) Planch	Virginia creeper	17	0.9	44	7.4	23	1.0
Rhus toxicodendron L	Poison ivy	6	0.1	1	0.1	3	0.1
Sanicula canadensis L	Black snakeroot	9	0.1	2	0.1	14	0.2
Rubus allegheniensis Porter	Mountain blackberry	3	0.4	2	0.1	14	0.6
Geum canadensis Jacq	White avens	7	0.1	6	0.1	26	0.6
Aster cordifolius L	Heartleaved aster	8	0.2	2	0.1	33	1.7
Rubus occidentalis L	Black raspberry	3	0.1	6	0.2	30	3.1
Galium concinnum T & G	Shining bedstraw	22	2.4	1	0.2	36	3.3
Carex cephalophora Muhl	Oval-headed sedge	13	1.8	12	1.0	37	9.0
Carex species§	Sedge	20	1.0	40	2.0	78	15.5
Poa pratensis L.	Kentucky blue-grass	—	—	25	4.6	45	11.8
Leersia virginica Willd	White grass	—	—	9	0.2	16	1.3
Lactuca canadensis L	Wild lettuce	—	—	—	—	17	0.8

*Based on 5 ungrazed woodlands; 41 quadrats.
†Based on 5 transition woodlands; 30 quadrats.
‡Based on 2 open-park woodlands; 16 quadrats
§Except *C. cephalophora* and *C. albursina*.

maidenhair fern, Virginia grape fern, wild rye grass, bottle-brush grass, lopseed, Solomon's seal, trilliums, nettles, bellwort, sweet cicely, white vervain, golden ragwort, wild geranium, sneezeweed, honewort, and waterleaf.

THE TRANSITION STAGE

The ground cover in the transition stage of both the oak-hickory and beech-maple types is composed of a high percentage of weeds. The reason for this is that the most palatable plants which occurred in the ungrazed condition have been destroyed and are replaced by less palatable ones. Moreover, in this stage the overhead stand has not been opened up sufficiently to permit the establishment of a dense and uniform cover of bluegrass. Under a moderate intensity of grazing the woodland may remain in this weed stage for from 10 to 20 years and during this period remains in a relatively unprofitable condition. It is an interesting fact that in most pastured woodlands the abundance of weeds is much greater than in open pastures. Welton and Morris (11) found 32% more weeds in a pastured woodland in Ohio than in adjacent open pasture. Field notes indicate that most livestock in the central states avoid all plants of the mint family, the arum family, the vervains, night-shades, the mustard family for the most part, may-apple, common mullen, moth mullen, milkweeds, dogbane, cinquefoil, bracken fern, the borage family, most of the parsley family, all species of dogfennel, thistles, sour dock, and most sedges.

The fact that woodlands in the transition stage contain a preponderance of weeds (Fig. 2) does not necessarily mean that soil conditions have become so seriously deteriorated that only weeds can persist. On the contrary, a number of these plants, such as Enchanter's nightshade, spotted touch-me-not, Indian turnip, and clearweed, are considered to be "nitrophyllous". Lutz (6) reports a similar situation in the early stages of grazing in a forest in Pennsylvania. This is attributed to the accelerated decomposition of the leaf litter and the deposition of dung which result in an increased nitrogen content of the soil. The presence of such plants in the transition stage seems inconsistent with the previous statement that succession is from moist to dry soil conditions. Rubel (7) suggests a possible explanation in his statement that, "increased soil nutrients may to some extent replace the effect of water. A heavily manured meadow produces a vegetation that closely resembles a very humid grassland." Further evidence that favorable soil conditions occur in transition woodlands is that following the exclusion of livestock farmwoods in this stage regenerate promptly and the tree seedlings make a very excellent growth.

In view of their very meager forage cover but excellent regenerative capacity, it follows that woodlands in the transition stage of grazing would be much more profitable if managed for timber production than for pasture. Such areas should be protected from livestock.

THE OPEN PARK STAGE

While it may appear from the above discussion that light grazing of virgin woodlands may have a beneficial effect on soil conditions,

FIG. 2.—A, The transition stage of the pastured woodland. The forage cover consists of a high percentage of weeds and sparse cover of bluegrass. B, The open park stage. Due to the increase in Kentucky bluegrass, the forage cover is better than in the transition stage but the shade from the forest trees lowers both the quantity and quality of the grass.

one needs only to follow through the succession which takes place under continuous and intensive grazing to see that this apparent improvement in site is merely temporary. Preliminary investigations of site conditions in ungrazed and open park woodlands and open pasture (3), indicate that during the dry periods the soil moisture content in the A, B, and C horizons of the open park woodland is lower than in either of the other two conditions. In the wooded pasture the factors which conserve moisture have been materially disturbed through the compaction of the soil surface, the disappearance of the protective forest litter, the elimination of the shrubby undergrowth, and tree seedlings which served as an effective barrier against free wind movements, and the formation of a sod cover. At the same time, the tremendous amount of transpiration which takes place in the dense forest has been only moderately lowered through reduction in the number of trees. An open grazed woodland of the oak-hickory or beech-maple type which is characterized by a crown canopy of around 50% and a compact soil surface will support certain species which are able to withstand dry and exposed conditions. As shown in Tables 1 and 2, the dominant plants in the open park stage of the oak-hickory and beech-maple types are Kentucky bluegrass, sedges, shining bedstraw, heartleaved aster, cinquefoil, white avens, violet, and others. Of these, the sedges and bluegrass have by far the greatest coverage.

Due to the increase in the amount of bluegrass (Fig. 2), the forage cover present in open park woodlands is of considerably greater value than that in the transition stage. This does not necessarily mean that open park woodland pastures are highly productive. While shade from forest trees is of some direct benefit to grazing animals, it lowers both the quality and quantity of forage. In Ohio it has been found that woodland pasture was 22% less nutritious than open pasture and that there was more than two and one-half times as much green weight of feed produced in the open pastures as in the woodland (11).

Studies based on periodic remeasurements of reproduction quadrats in open park woodlands protected from livestock indicate that natural tree reproduction, especially in the oak-hickory type, is subject to repeated failure. Consequently, in most cases, artificial methods must be employed if a growing stock of desirable species is to be built up. Preliminary studies in the artificial regeneration of an open park woodland indicate that furrows plowed at right angles to prevailing winds serve the double purpose of breaking up the heavy sod cover and holding the leaves which fall from the overhead stand (4). Tree seedlings planted in such furrows have a much better chance for successful establishment than if no cultural measures are taken to improve soil conditions.

SUMMARY AND CONCLUSIONS

Studies of the lesser vegetation which were made in seedling reproduction quadrats in grazed and ungrazed woodlands indicate that forage cover is decidedly inferior in the transition stage of grazing. In this stage the crown canopy still provides sufficient shade to prohibit the establishment of a uniform and dense cover of bluegrass and the

woodland may remain in this unproductive condition for a period of from 10 to 20 years. The ground cover consists mainly of weeds because the palatable plants which previously occurred in the ungrazed condition have been destroyed and are succeeded by less palatable species. Due to the low carrying capacity of transition woodlands and their excellent regenerative capacity following the removal of livestock, it is evident that such woodlands will be much more profitable if managed for timber than for pasture production.

While the ground cover of open park woodlands contains a higher proportion of bluegrass and fewer weeds than the transition woodlands, the overhead stand, with a density of 50% or more limits the yield and quality of the forage. Such areas are not only poor pastures but are also ruined woodlands. Due to the adverse environmental conditions for natural tree reproduction in many of these areas, artificial methods must be employed if a satisfactory stand of young trees is to be obtained within a reasonable length of time following the exclusion of livestock.

If through improved pasture management, the agronomist makes it possible for the farmer to raise the carrying capacity of his pastures, the less profitable woodland pasture may be retired from grazing and provisions made for its return to a thrifty forest condition.

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THE ACID-ARSENICAL METHOD IN WEED CONTROL[1]

A. S. CRAFTS[2]

MANY inquiries are received each year concerning the acid-arsenical treatment for killing deep-rooted perennial weeds. This paper attempts to clarify the status of this method by accurately describing the conditions and technic necessary for optimum results, pointing out factors that limit its use, and presenting additional data indicating certain improvements. Though practical in the semi-arid West, the general use of this method in more humid districts can only lead to disappointment if its limitations are not fully recognized.

MECHANICS OF ARSENIC ABSORPTION AND MOVEMENT

Experience has corroborated interpretations relating water balance in the plant to the absorption and movement of the arsenic spray. Continued use of the method has indicated more clearly the relative importance of certain factors such as the amount of absorbing leaf surface and the relation of transpiration and soil moisture deficit to water balance.

Although the experiments of Gray (14, 15),[3] Kennedy and Crafts (16), Crafts and Kennedy (11), Morgan (18), and Crafts (3, 4, 5, 6) indicate the conditions under which absorption and movement of arsenic take place, a brief resumé of the mechanics of the process seems timely.

When transpiration exceeds water absorption, a water deficit is developed throughout the plant and all living plant cells acquire the capacity to absorb water. If the plant with this water deficit in its tissues is rapidly killed, liquid is absorbed from the xylem vessels and their contents are replaced by any available water or by air. A strongly acid spray rapidly kills the foliage of plants, and if this spray contains arsenic there is presented a dilute arsenic solution for absorption into the xylem vessels. A virtual reversal of the transpiration stream occurs and all tissues infiltrated with the poison are killed. The acid-arsenical spray technic consists largely of fulfilling the requirements for the successful absorption and movement of arsenic from the sprayed portion of the plant into the root.

Since the competition between the plant and the soil for water is so important in the water balance of the plant, and hence in the mechanics of arsenic absorption and movement, the soil-plant water relation is vitally concerned. The root system of most higher plants can absorb water and supply it to the top with a force of only about two atmospheres. Since this force is inadequate, under field conditions, to meet the normal needs of the plant, most of the water absorbed from soils by higher plants is drawn in as a result of transpiration by leaves, a maximum force of about 16 atmospheres (19) being available for such absorption. The development of sufficient water deficit within the plant for action of the

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[3]Figures in parenthesis refer to "Literature Cited", p. 942.

mechanism responsible for downward movement of the arsenic depends upon water loss from the leaves.

With killing of the foliage, on the other hand, absorption of water by exploring root tips from regions of adequate soil moisture tends to supply the root system and satisfy the deficit which has been created by transpiration. The object in the successful use ot the acid-arsenical is to have this deficit satisfied by arsenic solution moving into the xylem vessels from the foliage rather than by water absorbed from the soil. Since absorption of water from the soil is relatively constant and cannot be affected by the operator, his control of the application is limited to manipulation of the volume of arsenic solution applied to the foliage. Since the evaporational losses from the sprayed tops may be excessive under conditions of high temperature and low humidity, it is essential that the spray solution penetrate the foliage rapidly and that the application be made after sundown, when these conditions are more favorable. Experiments have shown that, to be effective, the action of the acid-arsenical type of spray must be rapid. If the rate of penetration of the spray is reduced by low acidity, low temperature, or any other factor, the results are unsatisfactory.

The penetration rate of the spray as affected by its acidity, the poison content as controlled by arsenic concentration, and the moisture supply as related to volume of spray solution applied may all be accurately controlled by the operator. Finally, the volume of poison actually moving downward from the tops into the roots, as determined by temperature and evaporation, depends largely upon climatic conditions and may be controlled only by selection of the time of application. For these reasons, as stated above, spraying is largely done at night. Volume-concentration relations of the spray solution have been accurately determined (4, 5).

The relation of temperature, humidity, and wind velocity to evaporational loss after spraying has been recognized, but not being subject to control, has proved difficult to study. Since the average operator would probably rely upon his own judgment rather than make the detailed measurements necessary for an accurate estimate of the effects of these factors, the results of spraying under extreme conditions should be known. Experience has proved that high temperature, coupled with low humidity, or high wind velocity, or both, causes too rapid evaporation and, hence, poor results. What the limits may be in this case will depend largely upon local conditions and, in the absence of exact data, experience must be relied upon. Atmospheric conditions conducive to extreme evaporation are easily recognized and under these conditions the best expedient is to delay spraying until better weather.

The complex relation between soil moisture and water balance in the plant, and the effect this relation has on general development or the results of spraying, are important. In past publications a soil moisture deficit has been given as a requirement for successful treatment. Recognizing that a plant may actually drop its leaves as a result of moisture shortage, reducing the area available for absorption, a shift of emphasis seems advisable. The obvious requirements are a saturation deficit *within the tissues of the plant*, and an adequately developed foliage surface for absorption. The deficit may occur in plants in fairly moist soils providing the leaf surface is large and transpiration high. On the other hand, no matter how high the water deficit, if leaf surface is not adequate little spray will be absorbed and the treatment will fail.

EXPERIMENTAL WORK

The time, volume, and method of application are more easily studied. Results of some recent experiments follow. Forty square-rod plats were selected from a field containing 1½ acres of bindweed (*Convolvulus arvensis*). Only plats having an estimated infestation with a rating of 90% or more were used. The selected plats were fairly uniform and the plants were well grown and mature. Applications were made on the evenings of July 13 and 14, 1936, during dry, warm weather. Neither evening was windy, but temperatures were high and stayed up until well after sundown.

FIG. 1.—Results of spraying morning glory, *Convolvulus arvensis*, with an acid arsenical herbicide in July 1936.

The sprays were mixed in the field using a stock arsenic solution and commercial concentrated sulfuric acid (2, 4). A 3-gallon Vermorel knapsack sprayer was used, two dry cells and a flashlight being attached to provide illumination during the applications.

Table 1 presents the results on a series of 16 plats representing four treatments using varying volumes of solution and successive applications in those cases where more than 1½ gallons were applied. Fig. 1 illustrates the results obtained in these experiments.

Summarizing the results of these treatments, the average percentage of resprouting on the 1.5 gallon plats (Table 1) was 10, 17.5, 52.5, and 80 for the four examination periods. On the 3.0-gallon plats, the averages were 2.0, 2.5, 8.7, and 17.5; on the 4.5-gallon plats, 0.5, 1.7, 3.2, and 6.5; and on the 6.0-gallon plats, 0.5, 1.0, 2.0, and 5.0. From these data it is obvious that results can be significantly improved by increasing the volume applied, at least to 4.5 gallons. Adding results of nine additional 3-gallon plats and six 6-gallon plats that were

TABLE 1.—*Effects of acid-arsenical sprays upon bindweed; the relation of volume and time of treatment to effectiveness.*

Plat No.	Treatment						Initial infestation, July 10, 1936	Results, estimated percentage re-sprouting at indicated dates			
	Number of applications	Total volume, gallons	Time								
			P.M.	P.M	P.M.	P.M.		Aug. 28, 1936	Dec. 4, 1936	Apr. 1, 1937	May 12, 1937
A3	1	1.5	7:45	——	——	——	90	10	15	50	75
A4	1	1.5	7:45	——	——	——	90	10	15	50	75
B9	1	1.5	8:40	——	——	——	95	10	20	50	80
B10	1	1.5	8:40	——	——	——	95	10	20	60	90
Average	1	1.5					92.5	10	17.5	52.5	80
A10	2	3.0	7:55	8:50	——	——	90	2	3	10	15
A11	2	3.0	7:55	8:50	——	——	90	2	3	10	15
B5	2	3.0	8:35	9:40	——	——	95	1	1	5	15
B7	2	3.0	8:35	9:40	——	——	95	3	3	10	25
Average	2	3.0					92.5	2.0	2.5	8.7	17.5
A12	3	4.5	8:10	9:00	10:10	——	95	0	2	5	7
A13	3	4.5	8:10	9:00	10:10	——	90	0	1	5	5
B3	3	4.5	8:30	9:30	10:40	——	90	1	2	1	7
B4	3	4.5	8:30	9:30	10:40	——	90	1	2	2	7
Average	3	4.5					91.2	0.5	1.7	3.2	6.5
A14	4	6.0	8:15	9:10	10:20	12:00	90	1	1	2	5
A15	4	6.0	8:15	9:10	10:30	12:00	90	1	1	2	5
B1	4	6.0	8:20	9:20	10:30	12:10	95	0	1	2	5
B2	4	6.0	8:20	9:20	10:30	12:10	95	0	1	2	5
Average	4	6.0					92.5	0.5	1.0	2.0	5.0

treated during the same evenings but not shown in the table, no significant effect upon these averages occurs. While all previous experiments (4) had been limited to 3 gallons per square rod, an increase of 50% in this volume may safely be recommended, especially where the foliage is dense.

Table 2 shows the results on 22 more plats that were included in these treatments.

The first five plats reported in Table 2 were 3-gallon applications made after sundown and sprayed with water on the following morning. The averages of the values given (Table 2) are 2, 2.8, 5.4, and 12.8. Compared with the 3-gallon plats reported in Table 1, it seems doubtful if the differences are significant. In fact, where experiments are being made to measure differences that are of necessity small, many plats must be used and they should be as uniform as it is humanly possible to select, a fact that has been overlooked by some (17). In the experiments previously reported on this subject (4), a total of 66 plats were involved and they were extremely uniform, the crop having been produced by irrigation following discing in a young orchard.

The second group of plats listed in Table 2 shows the relation between time of application and effectiveness of the treatment. Sunset at this date was some time after 7:00 p. m. It is evident that the plats treated before this time yielded decidedly inferior results. Even increasing the volume to 6 gallons per plat (third group) did not eliminate this difference, though it did tend to increase effectiveness of the early applications as shown by the third group of plats.

Thinking that an early application when conditions favor rapid penetration might open up the plant and allow rapid absorption of a subsequent treatment, the plats listed in the fourth group of Table 2 were sprayed early and again later. In every case, however, results were poor, and especially was this true when the first spraying was done well before sundown. The plants on these plats were killed and discolored in less than half an hour. Evidently they dried out and the xylem vessels became blocked with air. Subsequent application of as much as 3 gallons of the spray solution failed to overcome the bad effects of this early treatment as shown by a comparison of plats B29 and C27. There seems to be no way to avoid the night application of the acid-arsenical spray.

LIMITATIONS AND ADVANTAGES OF METHOD

Field experience with the acid-arsenical method has shown further limitations in its use. First, it is practically impossible to obtain uniform maturity over areas of weeds not uniform in stand because of unequal distribution of the roots with respect to soil moisture. Plants at the edges of solid patches invariably mature slower than those in the centers and it is a common experience to have a "border effect" consisting of a row of resprouting plants around the edge of each infestation following treatment. The lateral roots of these plants, extending into unoccupied soil, tap a water supply unavailable to the plants on the inside.

TABLE 2.—*The relation of time and method of application of the acid arsenical treatment to killing of bindweed.*

Plat No.	Treatment				After treatment A.M.	Initial infestation, July 10, 1936	Results, estimated percentage re-sprouting at indicated dates			
	Number of applications	Total volume, gallons	Time				Aug. 28, 1936	Dec. 4, 1936	Apr. 1, 1937	May 12, 1937
			P.M.	P.M.						
A30	1	3	9:50	——	H_2O 3 gal.	90	0	1	5	15
B12	1	3	10:55	——	H_2O 3 gal.	95	5	5	10	25
B13	1	3	11:00	——	H_2O 6 gal.	95	1	3	7	10
B19	1	6	11:30	——	H_2O 3 gal.	90	2	3	3	7
B20	1	6	11:45	——	H_2O 6 gal.	90	2	2	2	7
Average	1						2.0	2.8	5.4	12.8
C3	1	3	5:05	——	——	90	10	20	60	80
C13	1	3	5:25	——	——	95	7	10	25	50
E23	1	3	6:20	——	——	90	2	4	10	15
C4	1	3	7:20	——	——	90	2	5	5	7
C12	1	3	7:30	——	——	95	2	2	5	10
E25	1	3	8:15	——	——	90	1	2	3	5
A31	1	3	10:00	——	——	90	0	0	2	5
C26	1	6	5:40	——	——	95	4	5	10	10
C27	1	6	6:40	——	——	90	2	3	5	7
C25	1	6	7:40	——	——	95	1	1	2	5
E26	1	6	8:20	——	——	90	1	1	3	5
B17	1	6	11:15	——	——	90	0	1	1	5
C10	2	3	5:15	7:10	——	90	10	20	50	75
C11	2	3	5:15	7:10	——	90	25	30	75	90
B22	2	6	4:30	4:50	——	90	3	5	10	25
B29	2	6	4:55	7:00	——	95	3	5	10	20
E24	2	6	6:30	8:00	——	90	4	4	4	7

Furthermore, genetic variations invariably occur among populations of deep-rooted perennials coming from seed and spreading vegetatively, and there are also variations in the physical properties of soils resulting in wide differences in water-holding capacity and root penetration. These differences are inherent in any given area and cannot be avoided. In addition, rodents and insects injure both roots and foliage. Plants cut off by gophers often go dormant and do not appear above ground until the subsequent season.

Since the plants must be mature at the time they are sprayed, seeds usually ripen to insure reinfestation of the area. Experiments have shown that in uniform stands the spray may be applied before seed maturity and seeds green at the time of treatment fail to germinate. However, if this type of control is attempted, the time available for spraying is cut to a few days during the early summer. Since little or no residual effect is produced in the soil, seedlings that appear in the years following the treatment must be killed by subsequent cultural or chemical treatments or the areas will be rapidly reinfested.

In semi-arid regions in years of deficient rainfall the soil is often moistened to a depth of only 2 or 3 feet. The spring growth of morning glory is usually reduced under these conditions and experience has proved that results with the acid arsenical are disappointing. The current season's feeder roots are limited to this upper moistened soil and penetration of the arsenic solution does not occur below these. It is inadvisable, therefore, to use the acid-arsenical spray in years of notably deficient rainfall in areas where the subsoil has a moisture content at or below the permanent wilting percentage.

While experience in California indicates that effects of residual arsenic upon the soil following application of an acid-arsenical herbicide are not serious, plants growing in certain soils have proved sensitive to small amounts of soluble arsenic. Especially is this true in wind-blown or water-laid soil containing very little clay and low in iron oxides. It seems possible that repeated use of an acid-arsenical spray in regions where such soils occur may lead to trouble; at least the possibility should not be lost sight of.

The method is further limited by the poisonous nature of the arsenic, the corrosive nature of the sulfuric acid, and the fact that it must be applied at night. In regions of regular summer rains there is little hope of obtaining a proper water deficit within the plants, and in northern latitudes where days are short the plants may never reach a sufficient maturity.

The method has given the best results so far observed on Russian knapweed (*Centaurea repens*). Morning glory (*Convolvulus arvensis*) and alkali mallow (*Sida hederacea*) are intermediate in response. Treatment of the perennial grasses and of hoary cress (*Lepidium* spp.) in California has resulted in total failure.

While considering the characteristics of the method, it might be well to point out some of its obvious advantages and to view its possible uses from various angles. Sulfuric acid, white arsenic, and caustic soda are staple chemicals used in large quantities and are readily obtainable at reasonable prices. At current costs the acid-arsenical spray may be made up for as little as 1 cent per gallon, or

\$5.00 to \$7.50 per acre for the chemicals required for treating an average stand of morning glory. In certain regions where the arsenic and acid are produced as by-products of the smelting industry, costs might be cut considerably below this figure.

In addition to its easy preparation, this solution lends itself to large scale application by boom equipment. Where very large areas are involved, the ejector type of equipment recently developed for applying sulfuric acid to broad-leaved annuals in grain fields (1) might be used. Practically the only change required would be the use of discs of large orifice size in the nozzles. Calibration curves for such discs have been made and are available (13).

COMBINATION METHODS

In spite of its obvious limitations, a method so inexpensive, yielding such excellent results under proper conditions, should find wide use. The operator should learn to recognize the conditions necessary for success and make every possible use of the method, avoiding so far as possible its weaknesses. With this in mind, it might be well to consider the possible combinations of this method with others in common use.

In semi-arid regions where leaching of chlorates to a sufficient depth for successful control of perennials is dependent upon winter rains, variations in the annual precipitation render the chlorate method uncertain (8, 9, 10). If application is made in early winter, excessive leaching may lower the concentration in the soil, allowing survival of the plants. If application is delayed, scanty rainfall may provide insufficient leaching and resprouts may push up from below the chlorate-containing soil layer. If the plants could be killed uniformly to a depth of 2 feet or more by the acid-arsenical spray at a fraction of the total cost of the treatment, an early winter chlorate application should complete the work with much less liability of a total failure resulting from excess loss by leaching. A few experiments of this nature have been reported (9).[4] The combination method would seem logical wherever chlorate application is subject to the uncertainties of rainfall.

In the use of carbon disulfide loss of the vapor by volatilization limits the placement of the chemical to a depth of at least 6 inches in most soils. Under certain conditions of sub-irrigation or winter application, plants in the top layer survive the treatment. A previous spraying with the acid arsenical should greatly reduce the probability of such results and here the cost would be almost negligible in contrast to that of the main treatment. A check on this combination has proved its effectiveness. It seems possible that the acid arsenical may be widely used as a pre-treatment for carbon bisulfide. It certainly will allow a deeper placement of the carbon bisulfide, minimizing losses from the surface.

[4]These experiments have been repeated during the past winter with even greater success. Where the acid arsenical gives results in the region of 90 to 95% control, there is evidence that the chlorate dosage may be reduced from one-third to one-half.

The use of arsenic (2, 7, 10) and of boron compounds (2, 12) in soil sterilization is aimed primarily at annual weeds. If deep-rooted perennials infest the areas, these pests, having no competition from the normal population of annuals, usually thrive and completely invade the treated areas. If they are objectionable, it would seem logical to pre-treat with the acid arsenical and also to include some chlorate in the sterilization treatment in order that the perennials shall not nullify the effects of the surface treatment.

In a clean cultivation program (2), acid-arsenical treatment during the autumn preceding the cultural work considerably weakens the plants, eliminating some of the early spring work, and shortening the whole program. When cropping programs are planned (2), pretreatment with the acid arsenical will reduce competition in the early stages of growth of the smother crop and increase materially the chances for success.

While considering these combination treatments, it would be well to point out that where the acid-arsenical method alone is used there is little hope by repeating the application to improve materially the results of a single treatment during the same season. If the initial treatment has given any degree of success, it is practically impossible to obtain a uniform mature stand for retreatment during that season. On the other hand, when any other type of treatment of deep-rooted perennials is contemplated, a pretreatment by this relatively inexpensive method may increase greatly the chances for success, provided, of course, that the necessary requirements may be met. It seems therefore that acid-arsenical treatment, although distinctly limited in its field of usefulness, may enter in a real way into the final success of several of the other common methods of weed control. Though lacking the inherent advantages of the soil treatment method (8), it deserves a permanent place in the field of chemical weed control.

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EFFECT OF APPLICATIONS OF FINE LIMESTONE: I. THE YIELD AND NITROGEN CONTENT OF SWEET CLOVER AND ALFALFA GROWN ON SHELBY LOAM AND CLINTON SILT LOAM[1]

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THERE are many reports of experiments which show large increases in the yields of general farm crops due to the addition of limestone to soils varying widely in acidity. The general conclusion has been reached that the best results could only be obtained by a complete neutralization of the acidity of the surface soil and that this was essential for a permanent soil fertility.

Recently, however, some investigators (1, 3, 8, 9)[3] have found that by drilling small amounts of fine limestone with certain legume seeds on some acid soils yields were obtained which were similar to those secured by broadcasting large amounts of limestone. In 1927, McCool (8) obtained the first results on drilling fine limestone in the row with legume seeds on acid soils. The soil receiving 750 pounds of finely ground limestone in the row yielded as much alfalfa as those soils receiving larger amounts of limestone applied broadcast. Several years later as a result of more experiments (9), he concluded that 550 pounds of fine limestone drilled in the row with the seed was as satisfactory for the growth of alfalfa and sweet clover as 3 tons of limestone applied broadcast. McCool took a conservative attitude with respect to putting this method of applying limestone into practice since the soils used in the experiment responded differently to this method of application.

Albrecht (1) found that by drilling 500 pounds of fine limestone in the row with the seed on Gerald silt loam, yields of sweet clover were obtained which were as large as those secured by heavy applications of quarry-run limestone. Successful results have also been reported by farmer cooperators (1) in many parts of Missouri by drilling fine limestone with red clover, sweet clover, and alfalfa on various soil types having different degrees of acidity.

It is fairly well established now that certain legumes, when fine limestone is drilled with the seed, do grow satisfactorily on some acid soils. Previous investigators have found legumes to respond differently on different soils when limestone was applied in the row. Since the practice of drilling small amounts of fine limestone with legume seeds on acid soils to promote the growth of legumes is becoming a more common practice, it seemed worth while to make such a study on some of the acid soils common to Iowa. This investigation was planned and a greenhouse and laboratory study made of the effects of fine limestone applied in the row with sweet clover and alfalfa seed

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[3]Figures in parenthesis refer to "Literature Cited", p. 959.

on the yield and total nitrogen content of the plants when grown on Shelby loam and Clinton silt loam.

EXPERIMENTAL

Two acid Iowa soils, a Shelby loam and a Clinton silt loam, were selected for the experiment, the surface soil only being employed. The lime requirement of the Shelby loam as determined by the Lewis-Hardy (6) method was 3.0 tons per acre, and for the Clinton silt loam the lime requirement was 2.3 tons per acre. The pH of the Shelby loam was 5.40 and the total nitrogen content was 3,270 pounds per acre. The Clinton silt loam had a pH of 5.78 and a total nitrogen content of 3,678 pounds per acre. The pH measurements were made with the quinhydrone electrode, and the total nitrogen content of the soils and plant material was determined by the Kjeldahl method.

The fine limestone used in the work was 95.5% $CaCO_3$ of which 98.5% passed through a 100-mesh screen. A 20% superphosphate was used.

The plants were grown in the greenhouse and during the winter months artificial lights were employed about 8 hours per day.

The experiment was divided into two series, the Shelby series and the Clinton series. The boxes of each series were separated into two groups, each group containing one box of each duplicate treatment; thus, in the experiment there were two groups of boxes within each series. The boxes in each group were located in blocks in the greenhouse. The location of each box within a block was assigned by a randomization procedure. At 2-week intervals the boxes within blocks were re-randomized and their locations changed accordingly.

The soil was taken to the greenhouse, air dried, screened through a ¼-inch sieve, and mixed thoroughly. Seventy-five pounds of soil were placed into each of 32 large wooden boxes, 12 in. x 18 in. x 12 in. The soils, regardless of limestone treatment, received an application of superphosphate at the rate of 200 pounds per surface acre. The soils receiving fine limestone applied broadcast were also treated at this time according to the outline given in Table 1. The moisture content of the soil was adjusted to 20% on the air-dry basis and maintained at approximately that amount throughout the experiment by additions of distilled water. The soils were moistened and two weeks later inoculated alfalfa and sweet clover seeds were planted. The seeds were planted in three rows, each row being 12 inches long and 6 inches apart.

The method of applying fine limestone beside the row was to apply one-half of the desired amount ½ inch on each side of the row at the same depth as the seed. All seeds were sown ⅔ inches deep and the growth in all boxes thinned down to 30 plants per box. The growth of the plants was measured 30 days after planting and at definite intervals thereafter until the first harvest. The plants matured 120 days after they were planted. At this time they were harvested, dried to 5% moisture, weighed, ground, and analyzed for total nitrogen. The nitrogen content of the plants was calculated on the oven-dry basis.

Soil samples for pH determinations were taken at the time the plants were first harvested. The second cutting was made 8 weeks after the first and the third cutting 7 weeks after the second. In all cases the plants were harvested when approximately one-tenth of the plants were in the stage of inflorescence. All crops were harvested and treated in the same manner.

TABLE 1.—*Outline of treatments.*

Treatment, acre basis	Shelby loam		Clinton silt loam	
	Pot No.	Crop	Pot No.	Crop
No treatment	1 2	Sweet clover	17 18	Sweet clover
	3 4	Alfalfa	19 20	Alfalfa
500 lbs. fine limestone in the row	5 6	Sweet clover	21 22	Sweet clover
	7 8	Alfalfa	23 24	Alfalfa
500 lbs. fine limestone beside the row	9 10	Sweet clover	25 26	Sweet clover
	11 12	Alfalfa	27 28	Alfalfa
Fine limestone applied broadcast*	13 14	Sweet clover	29 30	Sweet clover
	15 16	Alfalfa	31 32	Alfalfa

*6,015 pounds per acre for Shelby loam and 4,550 pounds per acre for Clinton silt loam.

RESULTS

SHELBY LOAM

The growth of the plants.—The height of plants in inches, as determined on each box at intervals of 30, 50, 64, 78, 92, and 106 days after planting, is shown in Table 2. Thirty days after planting very little difference was observed in the mean height of the plants irrespective of treatment. This seems to indicate that germination and early plant growth were not delayed when fine limestone was applied to the soil with the seed. Sixty-four days after planting, and from that time on until they were harvested, the plants on the soils receiving no limestone were distinctly smaller than those grown on soils receiving limestone. After 64 days, the growth of alfalfa on the soils receiving limestone applied broadcast was greater than that obtained on any of the other soils in the experiment. In general, where fine limestone was applied to the soil in the row and beside the row, plants approached the height of those grown on fully limed soil.

The pH determinations of soil at the time of harvest.—The average pH of the soils at the beginning of the experiment was 5.40. In sampling the soils for pH determinations a 1-inch metal cork borer was used and samples were taken in the row at 1 and 2 inch depths. Duplicate samples were taken from each box. The results obtained are presented in Table 3. The surface inch of soil was neutral in reaction

TABLE 2.—*Height in inches of sweet clover and alfalfa grown on Shelby loam.*

Treatment, acre basis	Crop grown	Block	Days after planting					
			30	50	64	78	92	106
No treatment	Sweet clover	A	1.8	2.2	3.0	6.0	8.0	11.6
		B	1.8	2.3	3.3	5.4	7.2	11.2
		Mean	1.8	2.3	3.2	5.7	7.6	11.4
	Alfalfa	A	1.7	2.4	3.5	5.5	7.6	11.2
		B	1.8	2.5	3.3	4.7	6.4	10.2
		Mean	1.8	2.5	3.4	5.1	7.0	10.7
500 lbs. fine limestone in the row	Sweet clover	A	1.8	2.3	3.3	6.2	7.6	11.6
		B	1.7	2.3	3.5	6.2	9.1	12.6
		Mean	1.8	2.3	3.4	6.2	8.4	12.1
	Alfalfa	A	1.9	2.3	3.4	6.1	8.8	12.0
		B	1.9	2.4	3.5	5.7	9.2	10.6
		Mean	1.9	2.4	3.5	5.9	9.0	11.3
500 lbs. fine limestone beside the row	Sweet clover	A	1.8	2.3	3.4	6.0	8.2	13.0
		B	2.0	2.6	3.6	6.6	10.0	13.0
		Mean	1.9	2.5	3.5	6.3	9.1	13.0
	Alfalfa	A	1.9	2.9	3.4	5.8	8.5	12.3
		B	1.9	2.5	3.0	5.4	8.1	11.7
		Mean	1.9	2.7	3.2	5.6	8.3	12.0
6,015 lbs. fine limestone applied broadcast	Sweet clover	A	1.7	2.0	3.7	6.1	9.2	13.0
		B	1.7	2.2	3.5	6.5	9.0	12.6
		Mean	1.7	2.1	3.6	6.3	9.1	12.8
	Alfalfa	A	1.8	2.7	3.8	6.5	10.8	12.6
		B	1.7	2.1	3.2	5.7	8.0	12.0
		Mean	1.8	2.4	3.5	6.1	9.4	12.3

where the sample had been taken in the row where 500 pounds of fine limestone had been applied. The pH of the sample taken from the second inch where fine limestone was applied in the row, however, was very nearly the same as that of the soils receiving no treatment. This indicates that the limestone had not neutralized the soil below the first inch. The results obtained from this portion of the experiment indicate that in 120 days the limestone had neutralized only the upper 1 inch where limestone had been applied in the row or beside the row.

Dry weight and nitrogen content of plants.—The yield and nitrogen content of sweet clover and alfalfa grown on the variously treated soils are shown in Table 4. An analysis of variance was made on the yield and nitrogen content of the plants. The results are given in Table 5.

TABLE 3.—*The pH of soils 120 days after seeding sweet clover and alfalfa on Shelby loam.**

Treatment, acre basis	Region of sampling	Block	pH after growth of crop	
			Sweet clover	Alfalfa
No treatment	In the row 0 to 1 in. deep	A	5.41	5.41
		B	5.45	5.39
		Mean	5.43	5.40
	In the row 1 to 2 in. deep	A	5.44	5.36
		B	5.44	5.28
		Mean	5.44	5.32
500 lbs. fine limestone in the row	In the row 0 to 1 in. deep	A	7.22	6.94
		B	7.07	7.09
		Mean	7.09	7.02
	In the row 1 to 2 in. deep	A	5.48	5.52
		B	5.54	5.46
		Mean	5.51	5.49
500 lbs. fine limestone beside the row	In the row 0 to 1 in. deep	A	6.25	6 26
		B	6.05	6.26
		Mean	6.15	6.26
	In the row 1 to 2 in. deep	A	5.57	5.49
		B	5.62	5.65
		Mean	5.60	5.57
6,015 lbs. fine limestone applied broadcast	In the row 0 to 1 in. deep	A	7.33	7.40
		B	7.36	7.36
		Mean	7.35	7.38
	In the row 1 to 2 in. deep	A	7.23	7.46
		B	7.28	7.32
		Mean	7.26	7.39

*The average pH of this soil before treatment was 5.40.

An analysis of variance on the dry weights of sweet clover and alfalfa tops of the first cutting showed that there was not a significant difference between the plants grown on the unlimed soils and those grown with fine limestone applied beside the row. However, the total nitrogen content of the plants was highly significantly greater where limestone was applied to the soil beside the row. In the second and third cutting both the dry weight and the total nitrogen content of the plants grown on soil receiving limestone beside the row were highly significantly greater than the plants grown on the untreated soil. In the first cutting the dry weight of the plants grown on soils receiving limestone applied broadcast was significantly greater than the weight of the plants on soils receiving 500 pounds of fine limestone

TABLE 4.—*The yield and nitrogen content of sweet clover and alfalfa grown on Shelby loam.*

Treatment, acre basis	Block	First cutting				Second cutting				Third cutting				Roots, dry weight, grams	
		Sweet clover		Alfalfa		Sweet clover		Alfalfa		Sweet clover		Alfalfa			
		Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Sweet clover, grams	Alfalfa
No treatment	A	20.0	588.0	16.3	456.4	18.2	660.6	16.9	525.6	16.5	648.5	17.5	561.8	14.0	34.0
	B	19.0	575.7	15.3	452.9	16.9	667.6	15.6	474.2	16.0	660.8	16.7	532.7	13.0	33.0
	Mean	19.5	581.8	15.8	454.6	17.6	664.1	16.3	499.9	16.3	654.7	17.1	547.3	13.5	33.5
500 lbs. fine limestone in the row	A	21.3	713.6	21.5	694.5	22.6	827.2	23.9	748.1	26.0	1029.6	26.5	792.4	20.0	35.0
	B	22.2	739.3	19.4	624.7	24.0	830.4	21.3	666.7	28.8	1105.9	27.7	855.9	18.5	34.0
	Mean	21.75	726.4	20.45	659.6	23.3	828.8	22.8	707.4	27.4	1067.8	27.1	824.2	19.3	34.5
500 lbs. fine limestone beside the row	A	19.2	672.0	18.4	544.6	24.1	908.6	20.9	660.4	24.9	941.2	21.0	678.3	13.5	29.5
	B	20.0	680.0	17.2	543.5	25.2	922.3	21.5	612.8	26.7	993.2	20.5	596.3	16.7	28.5
	Mean	19.6	676.0	17.8	544.0	24.7	915.5	21.2	636.6	25.8	967.2	20.8	637.4	15.1	29.0
6,015 lbs. fine limestone applied broadcast	A	22.4	768.3	20.9	698.1	29.7	1098.9	25.9	823.6	31.0	1230.7	27.8	950.8	20.5	36.0
	B	23.4	800.3	19.8	702.9	30.3	1124.1	23.3	764.2	32.5	1287.0	27.0	945.0	22.3	34.5
	Mean	22.45	784.3	20.35	700.5	30.0	1111.5	24.6	793.9	31.8	1258.9	27.4	947.9	21.4	35.3

TABLE 5.—*Analysis of variance of the dry weight and nitrogen content of tops of alfalfa and sweet clover grown on Shelby loam.*

Source of variation‡	Degrees of freedom	Mean square						
		First cutting		Second cutting		Third cutting		Roots, Dry weight
		Dry weight	Total N	Dry weight	Total N	Dry weight	Total N	
Between blocks	1	0.06	16.8	1.05	2,272.9	1.38	1,290.6	0.25
Between crops	1	21.86**	41,973.7**	29.43**	194,503.0**	19.58**	245,892.0**	992.25**
Between treatment								
L_r-L_s	1	11.52**	13,769.7**	0.001	125.6	31.60**	41,270.6**	46.56**
$2L_f$-L_r-L_s	1	7.93*	22,019.0**	50.75**	87,013.0**	49.59**	140,148.1**	39.78**
$3L_o$-L_r-L_s-L_f	1	24.22**	80,270.3**	168.37**	187,912.7**	301.50**	366,643.0**	15.18*
Treatment X crop	3	1.08	1,031.7	4.60	8,107.8**	8.55**	10,147.2*	8.45*
Error	7	0.77	483.4	1.35	957.0	0.98	1,490.6	1.54
Total	15	4.95	10,968.5	18.19	33,556.6	29.08	55,741.3	75.34
L_o-L_s	1	2.20	16,854.4**	—	—	87.12**	—	—
$2L_o$-L_r-L_s	1	—	—	97.20**	96,330.0**	—	—	—
L_f-L_r	1	—	—	—	—	10.81**	—	—
L_o-L_r	1	—	—	—	—	—	—	14.79**

*Significant.
**Highly significant.
L_o = No treatment.
L_r = 500 pounds fine limestone in the row.
L_s = 500 pounds fine limestone beside the row
L_f = 6015 pounds fine limestone applied broadcast.

in the row or beside the row. This difference was highly significant in the second and third cuttings. The dry weight of the plants grown on soils with fine limestone applied in the row was highly significantly greater than in the case of crops grown on soils with limestone applied beside the row at the first and third cuttings. A highly significant difference was also found between the dry weight of the sweet clover and the alfalfa. The dry weight of all plants was highly significantly less on the untreated soils than on the soils treated with limestone.

At the third cutting the dry weight of the plants grown on the fully limed soil was highly significantly greater than that of the plants grown on the soil receiving limestone in the row. At the second and third cuttings the alfalfa and sweet clover did not respond the same to the liming treatments. This is shown in Table 5 where there is a highly significant difference in treatment X crop. This may be explained by the fact that sweet clover is a biennial and was probably affected differently than alfalfa by several cuttings. The differences in the dry weight and total nitrogen content of the plants are much greater between treatments in the third cutting than they are in the first and second cuttings; however, the same general relationship exists between the treatments and the crop growth. Large gains in both the yield and nitrogen content of the plants may be noted from the first cutting to the third cutting, especially where limestone was applied broadcast to the soil.

The data in Table 4 show that the dry weight of sweet clover was the greatest where fine limestone was applied broadcast to the soil at the rate of 6,015 pounds per acre and the smallest where no limestone was applied. Where fine limestone was applied in the row, the yields of sweet clover approached those on the fully limed soils. The yield of sweet clover increased from the first cutting to the third cutting on soils receiving limestone, while the yield on the untreated soils decreased. On the soils receiving no limestone the smallest crop of alfalfa was produced while on the fully limed soils and the soils receiving fine limestone in the row, the highest yields were obtained. The dry weight of the third cutting of alfalfa grown on the soil receiving limestone in the row was practically the same as where the limestone was applied broadcast; however, the total nitrogen content of the alfalfa grown on the fully limed soil was greater.

These results indicate that the yields of sweet clover and alfalfa grown on Shelby loam receiving small amounts of fine limestone in the row may approach those of the same crops grown on fully limed soils.

The total nitrogen content of the plants grown on the fully limed soils was greater in all cases than with those grown on any of the other soils in the experiment. A statistical analysis shows that this difference is highly significant. The results agree with those obtained by Joffe (7) and by Walker and Brown (11), who concluded from their experiments that the highest protein content of legumes was secured on soils receiving limestone applications equivalent to their full lime requirement. The plants grown on soils receiving no treatment contained less nitrogen than plants grown on the treated soils, the difference being highly significant. The general trend of the results is for both the percentage of nitrogen and the total nitrogen content of the

plants to increase in the following order of treatments: no treatment, limestone beside the row, limestone in the row, and fully limed soils.

It may be observed in Tables 4 and 5 that the dry weight of the roots of the plants responded to the treatments in the same manner as did the tops. Larger differences may be noted between treatments in the sweet clover roots than in the alfalfa roots.

It appears from this experiment that, although the dry weights of the plants grown with fine limestone applied in the row approached those where the plants were grown on fully limed soils, yet the nitrogen content was highly significantly less. This probably is a result of conditions being less favorable for the nitrogen-fixing bacteria in the partially limed soils.

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The growth of the plants.—The height of the plants as measured at regular intervals is given in Table 6. The limestone applied broadcast and in the row seemed to be slightly depressive to the growth of alfalfa when determinations were made 30 days after planting. This effect had disappeared, however, 50 days after planting. Applying limestone broadcast appeared to have some depressive effect on the growth of sweet clover until approximately 64 days after planting. After this time the height was comparable to that of plants on soil receiving other treatments. The only distinct difference in height of the plants at the time of harvest was between those grown on soil receiving limestone and those on soil receiving no limestone.

The pH determinations of the soil 120 days after seeding—The pH values of the soils at the time of harvesting the first crop are given in Table 7. The average pH of the soils at the beginning of the experiment was 5.78. The surface inch of soil where limestone was applied in the row was nearly neutral and the pH was about the same as in the case of the samples taken from the fully limed soil, whereas the soil where the limestone was applied beside the row showed a pH of about 6.3. The limestone when applied in the row or beside the row did not move down into the second inch of soil as indicated by the pH determinations.

Dry weight and nitrogen content of plants.—The dry weight and nitrogen content of the plants grown in this experiment are recorded in Table 8. An analysis of variance was made of this data and the results shown in Table 9.

In the first crop the greatest dry weight and total nitrogen content of sweet clover was secured on the soils to which limestone was applied beside the row. However, for the growth of alfalfa, taking all three cuttings into consideration, limestone applied in the row and beside the row had practically the same effect. The analysis of variance of the data for the first and second cuttings showed no significant difference between the dry weight and the nitrogen content of plants on soils receiving limestone in the row and those on soils receiving limestone beside the row. The dry weight and nitrogen content of the plants grown on soils receiving limestone beside the row was highly significantly greater in the third crop than where limestone was applied in the row. In the first crop there was no significant difference

TABLE 6.—*Height in inches of sweet clover and alfalfa grown on Clinton silt loam.*

Treatment, acre basis	Crop grown	Days after planting						
		Block	30	50	64	78	92	106
No treatment	Sweet clover	A	2.0	2.8	3.4	5.8	8.1	10.6
		B	2.0	2.5	3.3	6.0	8.5	12.3
		Mean	2.0	2.7	3.4	5.9	8.3	11.5
	Alfalfa	A	1.8	2.4	3.2	5.2	7.3	11.0
		B	2.2	2.8	3.6	6.0	9.3	10.6
		Mean	2.0	2.6	3.4	5.6	8.3	10.8
500 lbs. fine limestone in the row	Sweet clover	A	2.0	2.5	3.7	6.8	10.5	14.0
		B	2.0	2.5	3.6	6.6	9.5	12.4
		Mean	2.0	2.5	3.7	6.7	10.0	13.2
	Alfalfa	A	1.8	3.0	3.6	6.0	10.0	12.6
		B	1.6	2.6	3.4	6.6	10.0	11.6
		Mean	1.7	2.8	3.5	6.3	10.0	12.1
500 lbs. fine limestone beside the row	Sweet clover	A	1.9	2.2	3.4	6.3	8.8	12.3
		B	1.8	2.6	3.6	6.5	9.2	13.1
		Mean	1.9	2.4	3.5	6.4	9.0	12.7
	Alfalfa	A	1.9	3.0	3.8	8.0	11.2	12.0
		B	2.3	3.0	3.8	7.6	11.4	14.2
		Mean	2.1	3.0	3.8	7.8	11.3	13.1
4,550 lbs. fine limestone applied broadcast	Sweet clover	A	1.8	2.1	3.7	6.2	9.6	12.6
		B	1.8	2.5	3.5	6.6	9.2	13.6
		Mean	1.8	2.3	3.6	6.4	9.4	13.1
	Alfalfa	A	1.8	2.5	3.2	6.2	9.8	11.6
		B	2.0	2.9	3.8	6.6	10.4	12.4
		Mean	1.9	2.7	3.5	6.4	10.1	12.0

between the dry weight of plants secured on the fully limed soils and on the soil receiving no treatment. At the second and third cuttings, however, the crop yields were much larger on the fully limed soils than on any of the other soils. The dry weight of the first crop of plants grown on soils receiving limestone in the row and beside the row were highly significantly greater than on the fully limed and untreated soils.

These results show that for the first crop on this particular soil, small amounts of fine limestone applied in the row and beside the row gave larger yields than where the soils were fully limed.

At the first cutting the total milligrams of nitrogen was practically the same for the plants grown on the untreated, limed in the row, and

TABLE 7.—*The pH of soils 120 days after seeding sweet clover and alfalfa on Clinton silt loam.**

Treatment, acre basis	Region of sampling	Block	pH after growth of crop	
			Sweet clover	Alfalfa
No treatment	In the row 0 to 1 in. deep	A	5.76	5.68
		B	5.68	5.70
		Mean	5.72	5.69
	In the row 1 to 2 in. deep	A	5.66	5.64
		B	5.68	5.64
		Mean	5.67	5.64
500 lbs. fine limestone in the row	In the row 0 to 1 in. deep	A	6.89	6.69
		B	6.69	6.61
		Mean	6.79	6.65
	In the row 1 to 2 in. deep	A	5.79	5.65
		B	5.65	5.67
		Mean	5.72	5.66
500 lbs. fine limestone beside the row	In the row 0 to 1 in. deep	A	6.11	6.35
		B	6.38	6.39
		Mean	6.23	6.37
	In the row 1 to 2 in. deep	A	5.68	5.61
		B	5.60	5.67
		Mean	5.64	5.64
4,550 lbs. fine limestone applied broadcast	In the row 0 to 1 in. deep	A	6.97	6.85
		B	6.87	6.95
		Mean	6.92	6.90
	In the row 1 to 2 in. deep	A	6.85	6.98
		B	6.70	7.02
		Mean	6.78	7.00

*The pH of this soil at beginning of experiment was 5.78.

fully limed soils. The nitrogen content of the first and second crops of alfalfa was distinctly higher where the limestone was applied in the row, whereas the plants receiving limestone beside the row contained somewhat less nitrogen.

The third crop of alfalfa contained more nitrogen where grown on soil receiving limestone beside the row than where limestone was applied in the row. The analysis of variance shows that the first crop of plants grown on soils receiving limestone applied in the row and beside the row were highly significantly greater in nitrogen than on soils to which the limestone was applied broadcast. The data also show that in the first crop there was no significant difference in the nitrogen content of the plants grown on the fully limed soils and that of plants grown on soils to which no limestone was added.

TABLE 8.—*The yield and nitrogen content of sweet clover and alfalfa grown on Clinton silt loam.*

Treatment, acre basis	Block	First cutting				Second cutting				Third cutting				Roots, dry weight, grams	
		Sweet clover		Alfalfa		Sweet clover		Alfalfa		Sweet clover		Alfalfa			
		Dry weight, grams*	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Dry weight, grams	Total N, mgms	Sweet clover, grams	Alfalfa
No treatment	A	22.4	835.5	18.7	676.9	22.9	954.9	20.7	718.3	13.7	613.8	18.5	653.1	13.0	31.2
	B	23.3	843.5	19.6	723.2	24.5	1016.8	22.1	769.1	15.5	654.1	20.5	721.6	15.0	29.0
	Mean	22.85	839.5	19.15	700.0	23.7	985.9	21.4	743.7	14.6	634.0	19.5	687.4	14.0	30.1
500 lbs. fine limestone in the row	A	24.4	889.2	23.6	816.6	22.9	895.4	26.5	837.4	17.0	702.1	23.3	740.4	18.5	35.5
	B	22.6	811.3	24.6	821.6	23.8	885.4	28.0	884.8	19.5	737.1	25.5	803.3	16.5	38.5
	Mean	23.5	849.7	24.1	819.1	23.4	890.4	27.3	861.6	18.3	719.6	24.4	771.9	17.5	37.0
500 lbs. fine limestone beside the row	A	25.5	915.5	24.2	759.9	24.8	972.2	23.9	791.1	24.3	996.3	26.0	886.6	18.0	37.3
	B	24.4	900.4	23.6	759.9	26.9	1022.2	24.6	715.9	26.1	1020.5	30.0	939.0	20.5	40.5
	Mean	24.45	907.9	23.9	759.9	25.9	997.2	24.3	843.5	25.2	1008.4	28.0	912.8	19.3	38.9
4,550 lbs. fine limestone applied broadcast	A	23.5	867.2	19.9	704.5	29.6	1172.2	32.7	1043.1	36.8	1593.4	37.0	1221.0	21.0	37.0
	B	24.0	849.6	19.0	672.6	32.0	1193.6	29.9	1007.6	39.5	1639.3	38.2	1317.9	22.0	37.0
	Mean	23.75	858.4	19.45	688.5	30.8	1182.9	31.3	1025.4	38.2	1616.4	37.6	1269.5	21.5	37.0

*Oven-dry weight (5% moisture).

TABLE 9.—*Analysis of variance of the dry weight and nitrogen content of tops of alfalfa and sweet clover grown on Clinton silt loam.*

Source of variation	Degrees of freedom	Mean square						
		First cutting		Second cutting		Third cutting		Roots, Dry weight
		Dry weight	Total N	Dry weight	Total N	Dry weight	Total N	
Between blocks	1	0.08	422.3	3.80	767.2	20.70	11,348.4	3.51
Between crops	1	17.85**	59,536.0**	0.06	113,006.3**	44.22**	28,366.9**	1,251.39**
Between treatment								
L_r-L_s	1	0.78	0.5	0.01	0.3	55.65	92,514.5**	6.66
$2L_f$-L_r-L_s	1	16.83**	9,825.3**	92.04**	139,324.0**	516.15**	927,440.8**	3.15
$3L_o$-L_r-L_s-L_f	1	15.53**	5,852.0*	63.02**	22,689.6**	400.20**	454,176.9**	125.77**
Treatment X crop	3	5.25**	3,833.7*	7.75*	10,233.4*	8.59**	35,564.5**	4.81
Error	7	0.06	632.5	1.33	1,221.2	0.35	234.6	2.31
Total	15	4.73	6,112.1	12.75	21,002.4	71.00	108,145.5	94.74
L_f-L_s	1	—	—	—	—	—	465,226.5**	—
L_o-L_f	1	0.07	273.8	—	—	—	—	—
$2L_r$-L_o-L_f	1	16.66**	—	—	—	—	—	—
$3L_s$-L_r-L_o-L_f	1	15.76**	—	—	—	—	—	—
$2L_o$-L_r-L_s	1	—	11,059.6**	18.38**	309.6	—	—	—
L_o-L_r	1	—	—	—	—	36.55**	14,475.5*	54.08**

*Significant.
**Highly significant.
L_o = No treatment.
L_r = 500 pounds fine limestone in the row.
L_s = 500 pounds fine limestone beside the row.
L_f = 4550 pounds fine limestone applied broadcast

The roots responded to the treatments in the same manner as the tops. The dry weight of the roots of the plants grown on the soils receiving limestone were highly significantly greater than the roots of the plants grown on the untreated soils.

With the exception of the first crop, the general trend of the results is for the yield and total nitrogen content of the plants to increase in the following order of treatments: No limestone, limestone in the row, limestone beside the row, and fully limed soils.

It seems quite logical to conclude from the results of the first crop that a temporary overliming injury caused a decrease in plant growth and that this injury was overcome in the second and third crops.

From the results obtained in this experiment it appears that the small amounts of fine limestone applied in the row and beside the row on Clinton silt loam were only comparable to the fully limed soils at the time of the first harvest. After the first harvest the plant growth and nitrogen content on the fully limed soils were far superior to those grown on soils receiving the small applications of limestone.

DISCUSSION

Limestone applications to Shelby loam, irrespective of the method of application, gave crop yields which were much greater than those secured on the untreated soils. The plants grown on these soils receiving limestone also contained more nitrogen than those grown on the untreated soils. The general trend was for both the percentage of nitrogen and the total nitrogen content of the plants grown on Shelby loam to increase in the following order of treatments: No treatment, limestone beside the row, limestone in the row, and fully limed soils. These results agree with those obtained by many investigators (4, 5, 10, 12) showing the beneficial effects derived from limestone applications on acid soils.

The plants grown on fully limed Shelby soil contained more nitrogen than plants grown under any of the other treatments. This may be accounted for since it was noted at the time of harvest that these plants contained more nodules than any of the other plants. It has long been known that soils neutral in reaction are more favorable for the legume bacteria than more acid soils.

Albrecht and Davis (2), McCool (9), and others have reported yields of legumes secured from some acid soils receiving small amounts of fine limestone in the row to be comparable to those secured from fully limed soils. It was also found in this investigation that the yields of sweet clover and alfalfa grown on Shelby loam and Clinton silt loam approached those of the fully limed soils. The nitrogen content of these plants, however, was much less than in the case of the fully limed soils.

Although the row method of applying small amounts of fine limestone may be favorable for the growth of legumes, it may not be so desirable for nitrogen fixation.

It is quite probable that fine limestone applied in the row exerts most of its influence at the point of application. This opinion is supported by the fact that in these experiments the limestone did not

neutralize the soil in the area even 1 inch below the point of application. This work is confirmed by the results secured by Albrecht and Poirot (3), Wilson (13), and others in which it was found that the movement of limestone in soils is very slow.

Albrecht has pointed out that the greatest function of limestone is to furnish calcium for plant nutrition and that the resulting change in pH has little influence on plant activities. The present investigation shows that small amounts of fine limestone apparently do supply calcium for the nutrition of plants as shown by the large increases in crop yields. The change in pH of the soil, however, seems to be necessary to a good fixation of nitrogen. Consequently, while small applications of lime may make it possible to obtain a crop of legumes, efficient nitrogen fixation is only obtained by a complete neutralization of the acidity of the soil by the application of lime. This investigation further indicates that applying small amounts of fine limestone in the row with legumes do have possibilities on soils which are of medium acidity.

SUMMARY AND CONCLUSIONS

1. Two acid Iowa soils, namely, Shelby loam and Clinton silt loam, were selected for a greenhouse investigation of the effects of small amounts of fine limestone applied in the row with the seed upon the yield and nitrogen content of sweet clover and alfalfa.
2. The experiments were set up on a statistical basis and all boxes completely randomized. The plants were analyzed for total nitrogen by the Kjeldahl method.
3. The data obtained for the dry weight and nitrogen content of the plants were analyzed statistically according to the method of analysis of variance.
4. Limestone, irrespective of the method of application, did not depress the early growth of sweet clover or alfalfa grown on Shelby loam. Early plant growth was retarded, however, on Clinton silt loam when limestone was applied in the row or broadcast.
5. In general, fine limestone applied in the row on Shelby loam promoted plant growth, as measured by height, and this was the case also with full applications of lime applied broadcast.
6. Shelby loam which received the full limestone application produced highly significantly greater yields of sweet clover and alfalfa than the same soil receiving limestone in the row or beside the row. The nitrogen content of the plants showed an even greater difference in favor of the fully limed soils.
7. The statistical analysis showed that the total dry weight and total nitrogen content of sweet clover and alfalfa grown on the untreated soils employed in this experiment were highly significantly less than those secured on the soils receiving limestone. One exception to this was found when limestone was applied beside the row on Shelby loam. In that instance no greater yields were obtained than were secured on the untreated soil.
8. There was a greater number of nodules present on the roots of plants grown on fully limed soils than on any of the other variously treated soils.

9. The general trend of the results was for both the percentage of nitrogen and the total nitrogen content of the plants grown on Shelby loam to increase with the following order of treatments: No treatment, limestone beside the row, limestone in the row, and full lime.

10. The application of small amounts of fine limestone in the row greatly benefits the growth of sweet clover and alfalfa on Shelby loam and Clinton silt loam.

11. No movement of limestone was found as measured by determinations of pH made 120 days after the beginning of the experiment. This would indicate that the area most favorable for nitrogen fixation would be very small since fixation is greater in soils near neutrality.

12. The beneficial effects of small applications of fine limestone applied in the row are greater when measured by the total dry weight of the plants than when measured by the nitrogen content of the plants. Apparently, such treatments improve the conditions necessary for plant growth to a greater extent than they affect the nitrogen fixation.

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SIMPLIFYING AGRONOMIC TERMINOLOGY WITH THE PREFIX "DE-"[1]

CARLETON R. BALL[2]

A SCANNING of recent agronomic and other scientific literature shows opportunity for simplification in at least one particular. Certain long and cumbersome phrases may be replaced largely by a single simple word, used either as verb or adjective.

The words under consideration are verbs used to express the removal of an object, organ, substance, or quality. These words also are used as adjectives describing the processes of removal or the original objects after such removal has occurred. Pertinent examples are such words as "deflower" (to remove flowers), "dehull" (to remove hulls), "desilt" (to remove silt), "desprout" (to deprive of sprouts), and "dewater" (to remove water).

Unless such terms are employed, the idea can be stated only in a much longer phrase. Scientific papers contain many such phrases. For example, "the plants from which the flowers had been removed", "removal of the hulls from the kernels", or "the process of removing the sprouts". These would be replaced by such simple phrases as "the deflowered plants", "dehulling the kernels", and "the desprouting process", respectively.

There can be no objection, of course, to the longer phrases if used only occasionally or if printing expense is no object. When such phrases must be used from 10 to 100 times in a single paper, however, both expense and wearisome repetition may be worth considering.

Many groups of technical workers besides agronomists are interested in this problem because of the growing demand for brevity in abstracts as well as in original papers. Both this interest and the resulting trend are indicated by a survey of recent usage. The number of terms so used and the frequency of their use definitely are increasing.

Table 1 contains a list of such terms compiled merely by jotting down examples met with in ordinary reading and in editing agronomic abstracts. No special study was made of literature in any technical field. The list, however, contains words used by agronomists, animal husbandmen, aviators, chemists, economists, engineers, foresters, horticulturists, manufacturers, military men, pest exterminators, tax officials, and general writers.

The first column in Table 1 contains the infinitive, whether it was noted in use or not. The letters in parentheses indicate inclusion of some form of the word in the Standard (S) and/or Webster's International (W) dictionaries. The second column contains those forms of the root word actually observed in use. The numerals in parentheses record the number of times each form of the word was noted. The

[1]Contribution from the Extension Service, U. S. Dept. of Agriculture. Received for publication October 8, 1937.

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TABLE 1.—*Recent usage of deprivative verbs with the prefix "De-" in their different word forms and in different classes of publications.*

Verb	Form used and way applied	Kind of publication	Times used
To debark (SW)	Debarked (bark from tree wounds)	Technical	1
To debitter	Debittered (bitterness from lupine seeds), translation of German "entbitterten"	Technical	2
To deblossom	Deblossomed (blossoms from fruit spurs)	Technical	42
To debrush	Debrushing (brush from wood lots)	Technical	1
To disbud (SW)	Disbudded (53), disbudding (12), (buds from apple trees)	Technical (2)	65
To debug	Debugging (bugs from ergot)	Literary	1
To debunk (W)	Debunk (4), debunked (1), debunker (3), debunking (7), (bunk from art criticism, drama, farm issue, politics)	Literary (7) Press (6)	15
To debutton	Debuttoning (" buttons" from citrus)	Technical	1
To decode (SW)	Decode, decoded, decoding, (code from messages)	Press	Many
To decommission (W)	Decommissioned, decommissioning (commissions from ships)	Press and Navy Department	Many
To de-egg	De-egging (eggs from hen, ergot)	Literary Press	1 1
To de-emphasis	De-emphasis (emphasis from football)	Press	2
To de-English	De-English (English from youth through cartoon strips)	Literary	1
To defat (W)	Defat (1), defatted (13), defatting (4), (fats from cocoa), partly translated from German "entfettete"	Technical (2)	18
To deflower (SW)	Deflowered (flower from land, virtue)	Lit. and Tech.	2
	Deflowered (32), deflowering (23), (flowers from cotton plants)	Technical	55
To deforest (SW)	Deforested (10), deforesting (2), (forests from land)	Technical (5)	12
To defrock (SW)	Defrocked (vestments from clergy)	Press	1
To defrost (W)	Defrost, defrosted (frost from fruit, refrigerators, etc.)	Technical (2) Commer. press	2 Many
To defruit	Defruited (55), defruiting (44), (fruit from trees, shrubs, herbs)	Technical (7)	99
To deglume	Deglumed (glumes from oat kernels)	Technical	13
To degrade (SW)	Degraded (grade from lumber)	Technical (2)	1
	Degrades (noun, degraded lumber)	Technical	9
To degrease (SW)	Degreased (grease from bones, wool)	Technical (2)	9

TABLE I.—*Continued.*

Verb	Form used and wav applied	Kind of publication	Times used
To degum (SW)	Degummed (37), degumming (28), gum from flax and ramie fibers)	Technical (3)	65
	Degumming (adj., agent for removing gum)	Technical	13
To dehair (S)	Dehairing (adj., agent for removing hair)	Commercial	1
To dehorn (SW)	Dehorn (3), dehorned (10), dehorner (13, dehorning (33), (horns from cattle)	Technical (3)	59
	Dehorned (horns from legislation)	Technical	1
To dehouse	Dehousing (houses from slums)	Press	1
	Dishoused (house from spirits)	Literary	2
To dehull (W)	Dehull (1), dehulled (218), dehulling (41), (hulls from cereal grains)	Technical (19)	260
To dehusk (W, obs.)	Dehusked (husks from barley, oat kernels)	Technical	1
To de-ice	De-iced (ice from apparatus)	Technical	1
	De-icing (ice from airplane wings)	Press (2)	2
To de-ink (W)	De-inked (ink from printing paper)	Literary	1
To dejunk	Dejunking (billboards from landscape)	Literary	1
To delead (W)	Deleaded (7), deleading (9), (lead from chemical compounds)	Technical (2)	16
To delint (SW)	Delint (13), delinted (191), delinter (12), delinting (216), (lint from cotton seeds)	Technical (20)	432
To delist	Delist (listing from stocks)	Press	1
To delouse (W)	Delouse (3), delouser (1), delousing (5), (lice from humans); exclusive of War Department publications	Literary, Technical (5)	3 6
To deluster (W)	Delustered (luster from fabrics)	Commercial (2)	2
To demarry	Demarried (marriage from woman)	Literary	1
To demold	Demolding (mold from ergot)	Literary	1
To demoth	Demothing (moths from clothes)	Commercial	1
To demouse	Demousing (mice from premises)	Literary	1
To denicotine (W)	Denicotined (nicotine from tobacco)	Commercial	1
To denitrate (SW)	Denitrated (2), denitrating (3), (nitrates from compounds)	Technical	5
To derate (W)	Derating (tax rates from land)	Press (England)	2
To deresin	Non-deresined (resin from rubber)	Technical	1
To descent	Descented (scent from traps, etc.)	Technical	1
To deseed (W)	Deseed (2), deseeded (85), non-deseeded (2), deseeding (30), (seeds from flax and oat plants)	Technical (5)	119

TABLE 1.—*Concluded.*

Verb	Form used and way applied	Kind of publication	Times used
To desheath	Desheath (5), desheathing (2), (sheaths from sorghum plants)	Technical (2)	7
To desilt	Desilting (silt from water)	Technical (2)	2
To desprout	Desprout (1), desprouted (11), desprouting (12), (sprouts from potato tubers)	Technical (2)	24
To destain (W)	Destained (2), destaining (5), (stains from tissues)	Technical (3)	7
To desucker	Desuckering (suckers from maize)	Technical (3)	10
To detail	Detailed (11), detailing (16), (tails from cattle, lambs)	Technical (3)	27
To detassel (W)	Detassel (3), detasseling (14), (tassels from maize)	Technical (3)	17
To dethorn	Dethorning (thorns from brambles)	Press	1
To detin (SW)	Detinning (tin from cans)	Technical	1
To devalue (W)	Devalue, devalued, devaluing (value from money)	Literary Press	Many
To dewater (W)	Dewatered (3), dewaterer (1), dewatering (5), (water from chemicals)	Technical (4)	9
	Dewatered, dewatering (water from cofferdams, locks, etc.)	Press	Many
To dewing	Dewinged (1), dewinging (1), (wings from elm seeds)	Technical	2
To dewool (W)	Dewooled (1), dewooling (1), (1), (wool from fabrics)	Technical	2
To deworm (W)	Deworming (worms from ergot)	Literary	1

final phrase in the second column names the classes of objects from which such removal took place.

The third column indicates the classes of publications in which the recorded usage was observed. "Commercial" indicates descriptions or advertisements of manufactured articles "Literary" refers to magazines and books, other than technical. "Press" refers to newspapers, including agricultural papers "Technical" indicates all classes of scientific and technical publications, including journals, abstracting journals, federal and state bulletins and other serial issues, and technical books.

In column 3, the numerals in parentheses represent the number of times each different form was found in use. Where no numeral is inserted, a single form was noted, except where the word "many" occurs in the final column. In that case, very numerous examples of usage were noted but the actual number was not recorded. The fourth column shows the total number of recorded examples of usage for all the different word forms derived from each infinitive.

Sixty different infinitives are listed in Table 1. One or more word forms derived from each of 58 of these were observed in use in 159 different recorded publications. Forms of 2 of the 60, decode and decommission, were noted many times, but no actual count was made.

draws his examples from many sources, some of which, especially those of Russian origin, are commonly neglected. For the author's use of these sources, the reader will be thankful. As a pedologist, Polynov pays more tribute to the humus and peat problem than a geologist would have. In general, the author makes much of his extensive knowledge of pedology and mineralogy in his treatise on the cycle of weathering. This is very strikingly apparent in chapter III which takes up "The Silicon and Iron Cycles" and which includes a discussion of other elements, such as titanium, zirconium, tin, boron, and vanadium, and their rôle in the cycle of weathering.

In chapter IV "The Cycle of the Alkali and Alkaline Earth Metals, Chlorine, Sulfur, and Phosphorus" is presented. A very enlightning discussion is found on the residual and secondary products of weathering in conjunction with some of the elements considered in this chapter. The reactions involved in the intake of these elements by plants are featured more than one would expect in a treatise of this kind. The subject, however, is very neatly woven in with the general theme.

In chapter V, "Forms of the Crust of Weathering and Their Distribution", the author musters his wide knowledge of the accumulated facts about weathering and its products and formulates his own theories. He skillfully revamps the available knowledge, augments it with his own data and that of his Russian colleagues whose work is not accessible to the Western World, and develops the theory of the distribution of continental deposits. This theory is a logical sequence of the three cycles of weathering which Polynov expounds in this monograph. One must read the text to appreciate the novel features of the unique approach in the study of the geologic processes with special reference to weathering.

There are of course some weak spots, and these are felt much more because of the forceful way in which new thoughts are propounded in the pages of the monograph. Some of the new ideas are mere statements or are not fully developed. In general, however, one can easily disregard this and can not help but learn much from the scholarly presentation of this complex subject. The English readers owe a debt to the translator, Dr. Alexander Muir of the Macaulay Institute for Soil Research, for his painstaking effort. The Russian text was not available to the reviewer, and nothing can therefore be said as to how closely the translator followed the text. In some places one can feel the difficult task of the translator; on the whole, however, it reads very well.

The last four pages are taken up by the translator with a "Note on the Structure of Silicates". In this note Dr. Muir gives a review of the work of Brammall, Goldschmidt, Marshall, and others. A foreword by Dr. Ogg, Director of the Macaulay Institute, commends the work of Polynov.

Soils men, especially pedologists and geologists, will find this monograph highly valuable. (J. S. J.)

PLANT ECOLOGY

By Hilda Drabble. New York: Longmans-Green & Co. 142 pages, illus. 1937. $2.50.

THIS small volume is intended "to provide a readable introduction to the study of Ecology" and to be "supplementary to, not a substitute for, a general textbook of botany" Its elementary outlook is quite in keeping with the purpose stated. A short (six pages) first chapter on soil mentions briefly the constituents: water, mineral matter, organic matter and air; and classifies types: sandy, clay, loam, calcareous, siliceous, peat, and silt. A paragraph is devoted to each. The second (three pages) chapter on soil organism is devoted largely to the part played by bacteria in releasing nitrates and to evaluating in general terms these products.

The next six chapters treat succintly of plants in relation to water, nutrition, respiration, organography, and communal relationships and classification. These topics are covered in about 20 pages.

The remainder of the book is devoted to a study of plant communities—largely English, though some Scotch and Welsh habitats are mentioned. These are treated under the headings: Oakwoods; Beechwoods; Ashwoods; Pinewoods; Heaths; Moorland; Chalk Downs; Grass Lands; Marsh and Aquatic Plants; Fenland; Salt Marsh; Sand Dunes; Shingle, Arable Land and Weeds; Hedgerows; Rocky Shores; and Mountains and Cliffs. An eight-page chapter on Plant Succession is placed in the midst of these community descriptions. A short reference list follows with a brief series of "test questions" on the various chapters, an index to plant names, and a general index—the latter very short but adequate

The author succeeds in her endeavor to make "a readable introduction to ecology". The book gives clear and useful pictures of British plant communities, wastes no words, and would be found in the reviewer's pocket if he were making a trip to England; it would be an excellent concise guide to the botanical landscape Naturally, it has little appeal to the specialist as it is so truly elementary. (G P. VE.)

AGRONOMIC AFFAIRS

PROPOSED AMENDMENT TO THE CONSTITUTION

IT is proposed to amend Article VI of the constitution of the American Society of Agronomy as follows: "The Executive Committee of the Society shall consist of the President, the Vice-President, the Secretary-Treasurer, the Editor, the Chairmen of the two Organic Sections of the Society, and the two immediate past Presidents".

This proposed amendment will be presented to the Society for final action at the annual meeting in Chicago in December.

ALFALFA IMPROVEMENT CONFERENCE

A MEETING of the Alfalfa Improvement Conference will be held at the Hotel Stevens in Chicago on Wednesday, December 1, at 7:30 p.m., in conjunction with the meeting of the American Society of Agronomy.

NEWS ITEMS

FRANK D. GARDNER has retired as head of the Department of Agronomy at the Pennsylvania State College after 29 years of service.

PROF. G. N. STROMAN of the Department of Agronomy, New Mexico State College, State College, N. M., lost all books, reprints, bulletins, and other material in his library, together with nine years' data on cotton breeding and other work, in a fire which destroyed Wilson Hall at the New Mexico State College. Professor Stroman's interests lie in the field of general agronomy, cotton breeding, cotton genetics, biometry, maize genetics, and maize breeding, and any available reprints along these lines would be greatly appreciated by him.

DR. R. LAVERN MATLOCK, formerly Assistant Professor, University of Arizona, and Assistant Agronomist, Arizona Agricultural Experiment Station, since 1931, has been appointed Associate Professor of Agronomy at Texas A. & M. College where he will assist in crops teaching.

ACCORDING to the *New York Times*, DR. PAUL D. EMERSON, senior soil scientist of the Soil Conservation Service with headquarters at Huron, South Dakota, died from the effects of a rattlesnake bite in a lonely canyon about 8 miles from Rapid City, South Dakota, probably on September 17 while engaged in collecting soil specimens. From 1919 to 1932, Dr. Emerson was Associate Professor of Soils at Iowa State College and was author of "Principles of Soil Technology."

BEGINNING in February 1938, *Chronica Botanica* will be issued bi-monthly and no longer as a year book, with a reduction in the annual subscription from 15 to 7 guilders. The new *Chronica* will include the following: Scientific communications, including brief notes on recent research; discussions, announcements, and letters to the editor on botanical matters; programs and reports of international congresses; quotations from articles of timely interest; miscellaneous news items and herbarium and museum notes; personal items; and reviews of new periodicals and new books.

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WHY PLANT RESEARCH?[1]

FREDERICK D. RICHEY[2]

I SUPPOSE that most retiring presidents of this Society have surveyed the addresses of their predecessors looking for inspiration. I further suppose that many of them finished the task with an intense desire that they, too, might contribute something as worth while as that which they had surveyed. At least, that has been my experience.

President Salter, in his address last year, stressed the need for integrating the determined facts of agronomy in sane and successful agricultural planning. I agree with him as to the importance of this challenge to the agronomists of the future. I am certain, however, that he would agree equally with me that this is not the sole challenge. Tonight, therefore, I intend to consider why plant research must continue, and something of what it may be expected to accomplish. I know of no better way of anticipating the future than from the experience of the past

PLANT RESEARCH AND SURPLUSES

We have been confronted recently with something of an obsession about the responsibility of plant research for the crop surpluses that have been a plague to both our houses,—farmers and business, alike. Let us disclaim responsibility for the stimulated production due to high prices during and following the World War, and the bringing into cultivation of lands which never should have been plowed—and which were broken in spite of the recommendations of agronomists. Then let us admit fairly our part of the responsibility, and claim credit for it.

My thesis can be presented most easily by some examples. Let's look at the record. The hard-red-spring and durum wheat region was settled in the 70's and 80's. The early settlers brought with them the varieties of wheat which they had grown in their former homes in Eastern America and in Europe. Of these, Bluestem and Fife soon became predominant. The reputation of hard red spring wheat as the

[1]Presidential address delivered before the thirtieth annual meeting of the Society held in Chicago, Illinois, December 2, 1937.

[2]Chief of the Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D C

best bread wheat in the world was made with these varieties. We know that these early settlers sometimes were seriously afflicted with grasshoppers and drought. Complete failures sometimes occurred, but they were rather infrequent. And then another factor entered the scene.

Stem rust first made its appearance in a way to command widespread attention in the epidemic of 1904. It occurred again with devastating force in 1916, since when there have been several epidemics of varying intensity, culminating in the tremendous loss of 1935 and another almost as severe in 1937. Foot rots, bunt, leaf rust, scab, and black chaff also have appeared, and, while causing damage less spectacular than that by stem rust, they are more ubiquitous and may cause a greater total loss. Furthermore, the soils contain less humus than 50 years ago, with consequent greater damage from droughts of intensity equal to those of earlier years.

The spring-wheat farmers of today, then, are confronted with a situation or environment very different from that of their forefathers, and this change has occurred through the intensification and continuation of agricultural industry in this and adjoining regions.

What has plant research done about it? Well, it has found new crops to replace part of the wheat acreage, permitting diversification of risk and crop rotation with its many advantages. The Corn Belt has been extended north more than 100 miles. Soybeans introduced by plant scientists now are an important crop where former varieties could not be grown. Sweet clover, once considered a noxious roadside weed, is now an important pasture, rotation, and cash crop. Minnesota and southeastern South Dakota, formerly important centers of wheat production, now are better known for the corn and hogs they produce.

But to get back to wheat. As early as 1884, efforts to improve the varieties then generally grown were undertaken, at first by private individuals, and later by the North Dakota and Minnesota Agricultural Experiment Stations. Two varieties produced by these early efforts, namely, Powers' Fife, and Haynes' Bluestem, became very popular, and probably occupied not less than 75 per cent of the total wheat acreage of the area at the turn of the century. Other improved varieties, such as Glyndon and Preston, accounted for some improvement. The famous Marquis wheat was introduced in 1912 and 1913. Because of its early maturity, stiff straw, satisfactory yields, and high quality, it spread with unprecedented rapidity. In 1929 it occupied about 85 or 90 per cent of the total area in hard red spring wheat. Ceres wheat was distributed in 1926. Because of its great resistance to stem rust and drought, it has replaced about 8 or 9 million acres of other varieties, including some of the Marquis. Thatcher was released to farmers in 1933. About 20,000 acres of this variety were grown in the rust epidemic year of 1935, and probably ½ million acres were grown in 1937. As most of you know, farmers who grew Thatcher in these years produced nearly normal crops of wheat, whereas those who grew Ceres and Marquis suffered severe losses.

It is quite impossible to arrive at any good estimate of the dollar

value of such accomplishments as the discovery of the usefulness of sweet clover, or of the possibilities of growing corn and soybeans Agronomists, however, have provided fairly reliable yield comparisons of wheat varieties under controlled conditions at many stations for many years. Reasonably accurate estimates of acreage of each of the important varieties throughout a considerable part of the period under consideration also exist. It appears from these estimates that the use of improved varieties has resulted in an acre yield of hard spring wheat about 30 per cent above what the present farmers of the area would obtain were they obliged to grow the varieties prevalent 35 to 40 years ago. This means from 40 to 50 million bushels per year more wheat.

Now, in so far as 40 to 50 million bushels add to a burdensome surplus, it must be admitted that better varieties of spring wheat have contributed. It happens that there has never been more hard red spring wheat than we actually needed, and that during the past five years there has been a deficit. The important thing, however, is that the superiority of the present varieties has done little or no more than to prevent reductions in yield, which otherwise would have occurred due to diseases and depletion of fertility. There has been no real increase but a prevented decrease. Finally, the larger average yields are more the result of considerable superiority in unfavorable years than of slight superiority in all years. It follows that in some years there would have been practically no wheat in the area had the older varieties been grown- and, I for one, prefer an occasional surplus to an occasional bankruptcy.

What of the future? Notable progress has been made in controlling the ravages of stem rust, but note the time required Active work in breeding varieties resistant to stem rust goes back more than 30 years, and long before that it had been known that certain varieties were highly resistant. Practically nothing has been accomplished in controlling foot rot, and very little with respect to leaf rust, bunt, and other diseases. So it appears that plant research will be needed in this field for some little time to come even though no new problems present themselves

CURLY TOP AND A NEW INDUSTRY

The host-virus-insect relation in the curly top disease of sugar beets offers an excellent example of a number of points in my thesis. The record is replete with cases of the initiation of beet culture in western areas, the establishment of factories, and of ultimate failures because of curly top. Half of the factories in some western states have stood idle in some seasons because of this disease, threatening the entire beet industry in that area I wish to pass for the moment the progress plant research has made in the control of this disease, and to explore the cause of the difficulty.

Curly top presumably was widespread before it was recognized as a distinct sugar-beet disease in 1899. Apparently, from occasional and localized outbreaks, severity increased until, by 1917, the disease had become a limiting factor in production. Researches proved that the beet leafhopper (*Eutettix tenellus*) functions as the vector of the virus,

and is probably the sole natural agency of transmission. The occurrence of curly top is coextensive with the distribution of the leafhopper, and its seriousness in any season depends upon the size of leafhopper populations and their movement.

The environmental changes which brought the beet leafhopper to the foreground are the deterioration of range lands by overgrazing and farm abandonment, following the speculative agricultural attempts in areas which, because of rainfall and other conditions, were not suited for permanent, well-ordered farming. As the native grasses of the range lands adjacent to irrigated valleys were exterminated by overgrazing and disturbance of natural conditions, the ranges became invaded by introduced plants on which the leafhopper thrives and which are reservoirs of the curly-top virus. As the grasses which are non-hosts were displaced by these weed-host plants, the populations of the leafhopper increased. In many areas, notably Idaho, the breaking up of range areas for wheat or other small grain production, which was stimulated by grain prices during the World War, and the subsequent abandonment of these attempts in the post-war period, vastly extended the leafhopper-breeding ground, since the abandoned fields turned into practically solid stands of mustards, Russian thistle, and other leafhopper breeders. Conditions that favored overwintering and brought about early migrations produced the serious curly-top outbreaks. With the continued and progressive deterioration of the range, curly top has greatly increased in destructiveness in the past 20 years. Again we have a man-changed environment bringing its new problems for solution. What has man done about it?

The first curly-top-resistant variety introduced, U. S. 1, was grown on 200 experimental acres in 1933, and on 102,813 acres in 1935. In 1937, this variety, with other improved varieties introduced later, occupied at least 150,000 of the total 280,000 acres of beets where curly top is a factor. The record of these varieties is impressive. The first variety practically equalled European brands under non-curly-top conditions, and produced a much larger crop than non-resistant sorts in all but extreme exposures. The more resistant varieties which occupied the bulk of the acreage in 1937 have produced a profitable crop under very severe conditions. Although these varieties are not immune, and suffered a loss in potential yield of 20 to 25 per cent, at least the old story of total crop failure has not been repeated and districts previously abandoned are now again engaging in sugar-beet growing.

More was accomplished, however, than reviving an industry threatened with extinction. It was necessary to develop a seed enterprise for producing seed of the new varieties.—May I interject that the agronomists specializing in grasses will be confronted by this same necessity?—Beginning in a small way, with a little less than 800,000 pounds of U. S. 1 in 1933, this enterprise has grown by leaps and bounds to a production in 1936 of 5,249,000 pounds of seed of resistant varieties from 2,620 acres in Arizona, California, Nevada, New Mexico and Utah. In making control effective, therefore, many new problems concerned with initiating a seed enterprise arose and were successfully met.

The new varieties developed are not so disease-proof nor so adapted to all localities as to suggest that the job is more than well started. Furthermore, new requirements constantly arise after the varieties are introduced. Thus, curly-top-resistant varieties for use in California must also be compatible with an unusual agricultural situation in which beet plantings are made in the winter season. This makes all but the most refractory varieties bolt badly. For California areas, therefore, non-bolting needs to be yoked with curly-top resistance.

In the background at present, but not to be overlooked nor underestimated, is the possibility that the present resistant varieties may encounter new strains of virus which may change the situation overnight. In fact, strains already have been found to exist within the curly-top virus complex. Finally, curly-top resistance is, of course, not the whole of the sugar beet problem by any means, but it has served, I believe, to illustrate again some advantages of plant research. It seems clear that green pastures for the breeder of sugar beets will continue and must be pastured for some time to come.

FILLING THE SUGAR BOWL

The "sugar bowl" comprises a limited area in the delta of the Mississippi River, within which is grown most of the sugar-cane-for-sugar in the United States. Some sugar also is produced from cane in Florida, and the plant research I will now consider applied also to the cane grown extensively for syrup throughout the Southern States. It was in the sugar bowl, however, that the situation was acute,—that exceedingly fertile area formed through the centuries by erosion and sedimentation—those twin agencies which some of our good colleagues in the Soil Conservation Service so loudly bemoan. Here was a specialized agriculture producing a crop with which no other could compete in profits, and at the same time a crop which could be produced satisfactorily only on very limited acreages elsewhere. Here were millions of investment in the needed mills and machinery.

In this area, for more than 150 years, there has been a continuous procession of varieties. Canes have been introduced, have attained commercial prominence for a time, and invariably have failed and been replaced by varieties better adapted to the changed conditions. The most conspicuous causes of failure have been epidemics of plant disease to which the varieties were susceptible. Each varietal transition was marked by a drop in production followed by recovery as new varieties were found that were better adapted. The most recent example of failure and recovery was in the past 15 years. It was caused by sugarcane mosaic, introduced into the country probably about 1915. The disease caused no widespread damage at first, in fact was unrecognized until 1919. From then on, however, it spread rapidly, and by 1926, production of sugar had dropped from a level of 250,000 or 350,000 tons per year to 47,000 tons.

The logical means of meeting the problem seemed to be by the time-honored method of variety replacement. But this time, all available varieties appeared to be susceptible. In fact, all commercially-grown varieties collected from the major sugar-producing countries did prove to be susceptible.

Certain wild forms, however, did not become diseased. Moreover, a few seedling varieties, bred for another purpose and already abandoned as commercial varieties in their country of origin, were found to be less severely damaged by mosaic than the commercial varieties. These seedling varieties were only reasonably well adapted to our conditions, but were used as stop-gaps, and saved the industry from obliteration during the period needed for breeding varieties that would more nearly meet the requirements.

A cane-breeding station had been established in southern Florida by the Bureau of Plant Industry in 1919 to start the process of "nobilization" of the unprepossessing but vigorous and disease-resisting wild forms of sugarcane. The potentialities of this method of breeding are incompletely explored, but already varieties resistant to the mosaic disease and some other difficulties have been produced and introduced. As a result, the production of sugar recently has surpassed any previous record, and the estimate for the 1937 crop is over one-half million tons of sugar. The acre yield of sugar is five times what it was 10 years ago. The cane tonnage increase was over 300 per cent and the increase in sugar content of the cane was 50 per cent. For the present, at least, the new varieties have again restored the industry to a high level of efficient production.

This example is particularly striking because plant research literally saved an industry producing a product worth more than 20 millions a year upon which thousands of people depended for a living, and for which there was no satisfactory substitute And yet, though striking, this example is by no means unique.

In a very similar manner the lettuce industry of the Imperial Valley was literally saved by the development and introduction of varieties resistant to brown blight, and then later, when mildew threatened the crop, by the introduction of another variety resistant to both brown blight and mildew. Offhand, agronomists may not be inclined to think of this as a particularly significant accomplishment. But, resistant varieties were grown on 90,000 acres in 1936,—quite a lot of lettuce,—worth 16¾ million dollars. And from the consumer's point of view, this means that winter lettuce is a staple food for the many instead of a luxury for the rich as it otherwise would be.

The cantaloupe industry was threatened recently by powdery mildew. Today most of the 38,000 acres devoted to cantaloupes in the Imperial Valley and in Arizona grow U. S. powdery mildew-resistant cantaloupe No. 45, worth 5 million dollars a year And any of you who ate early cantaloupes the past summer almost certainly ate this variety.

Again, the tomato industry of Florida was saved by the introduction of Marglobe, resistant to wilt and nailhead rust. In 1927 there were 30,000 acres of this variety, worth 3 million dollars. Since then other superior varieties have been introduced which have partly replaced the Marglobe.

QUALITY AND ECONOMY OF PRODUCTION

Plant improvement rarely is devoted to the sole purpose of increasing yield. Quality is equally important. Rust and smut decrease both

the yield and the quality of wheat, and the gains in quality from the development of resistant sorts are frequently more important than the gains in yield alone. A few years ago practically all of the wheat from some of the shipping stations in the Pacific Northwest was very smutty, with consequent heavy dockage and a very low price. With the use of such smut-resistant varieties as Ridit, Albit, and Oro in these areas, most of the wheat now coming from the same stations is smut-free and without penalty. The spring wheat varieties Marquis, Ceres, and Thatcher, are without question superior in quality to the Haynes' Bluestem and Powers which they replaced.

Much of the work of our horticultural colleagues is directed toward improving the quality of fruits and vegetables. I refer not only to the development of new kinds by breeding and selection, but also to studies of fertilizer and cultural practice, time of harvest, and the like, that will be conducive to the greatest excellence of the product. They do not stop here, however. Studies of the relation of temperature and humidity to the physiological break-down and the development of organisms of decay have led to markedly more efficient methods of storage and transportation. Incidentally, by taking advantage of knowledge so gained, it was possible within the past few years to modify the practice of shipping citrus from California to the eastern seaboard with a resultant annual saving of about a million dollars in icing charges.

Not the least of the accomplishments of plant research have been its contributions which make the production of crops less expensive and farm labor less arduous. Modern corn hybrids are superior to the open-pollinated sorts even more in their ability to withstand lodging than in yield. Similarly, lodging-resistant varieties of small grains have been developed and sorghum varieties have been produced and introduced that can be harvested with a combine, and the objectional barbs have been removed from barley awns.

A very striking improvement in efficiency is the change that has taken place in the canned corn industry as the result of the introduction of sweet corn hybrids. It has been estimated that 80 per cent of the yellow sweet corn grown for canning in 1937 was produced from hybrid seed. The yields from these hybrids are higher, the crop ripens more uniformly thus permitting more economical harvesting, they are more resistant to bacterial wilt, and are of a better quality than any of the commercial sweet corn heretofore grown. The uniformity in texture and consistency of grain, and in shape and size of ears have encouraged changes in machinery, and methods of handling in the factory,—and have benefited the grower, the processor and the consumer alike.

NEW CROPS

Plant research has played an important role in discovering or developing new crops and in finding new uses for old crops. Mention has already been made of sweet clover, and most of you are familiar with the history of Sudan grass. The acreage of soybeans has increased from less than 50,000 acres 30 years ago to nearly 7 million acres in 1935, an increase due almost entirely to the introduction of new sorts from the Orient adapted to a wide range of different condi-

tions. The increase in this crop is particularly significant because of its extensive use for oil, food, and industrial purposes, and especially because soybeans have functioned, at least to some extent, in reducing the acreage of the surplus crops, oats and corn.

Crested wheatgrass was introduced to this country in 1898 but has just recently received belated recognition as a hay and pasture crop, for erosion control, and for reseeding abandoned acres in the northern Great Plains, and in Oregon and Washington. In the South, as far north as the Ohio River, are millions of acres of land that are no longer growing clover because of man's improvidence in not maintaining soil productivity. A study begun in 1919 showed the value of Korean lespedeza for this area, and as a result a large proportion of these infertile lands is now growing this crop. It is not only a source of many million dollars' worth of hay and pasture, but it is also improving the fertility of the soils and has proved to be a potent factor in controlling soil erosion. In Missouri it is a pivotal crop that bids fair to reduce the acreage of corn, and consequently the surplus of corn.

CONCLUSION

I have presented examples of successful plant research only from the field of applied research. It seems self-evident that there could have been no successful application unless the basic knowledge first were available. Speaking to plant scientists, I have not stressed this fact. But, the accomplishments of modern corn breeding rest directly upon advances in the science of genetics. The breeding for disease-resistant varieties involved the applications of the principles of genetics, physiology, and pathology. One could proceed at will.

It is, of course, impossible within the limits of this paper to give any adequate picture of all that plant research has accomplished in the past or of what it may be expected to accomplish in the future. I have tried to pick examples that would illustrate the debt which the public of today owes to the plant research of the past. I have, moreover, selected examples that permitted more or less concrete evaluation, ignoring many improved cultural and soil-management practices resulting from plant research. Finally, I have tried to illustrate the fact that, though plant research has accomplished much, those most familiar with its status recognize fully that it is only in its infancy and that it must continue indefinitely. Plant production is the basis of all agriculture and of all civilization. Mankind is engaged in a constant battle with nature to supply efficiently, adequately, and certainly those plant products which he needs for his sustenance and well-being.

In the past much of plant research has consisted in obtaining plants that were reasonably adapted to an environment which did not change rapidly. With a greater intensity of agriculture, more rapid transportation, and withal, with man's tendency to cash in today without thought of tomorrow, the environment changes more rapidly. It never was static, but it has become kaleidoscopic. If man is to win, he must be as versatile in his defense as nature is in her attack. This implies adequate ammunition that continued plant research alone can supply.

Plant research may well contribute to crop surpluses at times. But, if so, it will be incident to stabilizing production over wide areas or through the years, or it may be by saving other industries in the future as it has in the past. It is certain, however, that without continued and continuous plant research, adequate remedies will not be available to meet emergencies which will arise and which may lead to local or even national disaster.

EFFECT OF APPLICATIONS OF FINE LIMESTONE: II. THE YIELD AND NITROGEN CONTENT OF ALFALFA GROWN ON TAMA SILT LOAM FROM DIFFERENT AREAS[1]

A. A. KLINGEBIEL AND P. E. BROWN[2]

EXTENSIVE experiments have been conducted on acid soils to determine the effects upon plant growth of various amounts of limestone having different degrees of fineness. It is quite generally accepted that the finer the limestone is ground the more quickly it neutralizes the soil acidity. Previous investigations have also quite clearly shown that the largest yields of legumes have been secured where the lime requirement of the soil had been met. Some recent work, however, seems to indicate that it is not necessary to meet the full lime requirement of a soil in order to secure crop yields comparable to those obtained on fully limed soils.

Fellers (2)[3] found that small amounts of limestone were nearly as effective as larger amounts in raising the protein content of soybeans. Alfalfa grown on soils ranging in pH from 3.0 to 7.1 was reported by Joffe (5) to increase gradually in nitrogen content with the corresponding decreases in the hydrogen-ion concentration. Parker and Truog (8) advanced the theory that the amount of calcium absorbed by the plants is proportional to the protein formed.

In a series of greenhouse experiments Fred and Graul (3) concluded that broadcasting small amounts of limestone is far more economical than making large applications. White (10) observed that the calcium content of clover and sorrel was highest where the maximum amount of limestone was applied and that both calcium and nitrogen in the two crops were higher when grown on an alkaline soil than on an acid soil.

In studying the effects of inoculation and liming on alfalfa grown on Grundy silt loam, Walker and Brown (9) secured the largest increases in yields on the plats where sufficient limestone had been applied to correct the soil acidity. The greatest amount of protein produced per acre was obtained as a result of liming and inoculation.

In some recent work carried out at the Iowa Agricultural Experiment Station (6), it was found that soils receiving limestone applied broadcast in amounts equivalent to the lime requirement of the soil produced highly significantly greater yields of sweet clover and alfalfa than the same soils receiving 500 pounds of fine limestone applied in the row. The nitrogen content of the plants showed an even greater difference in favor of the fully limed soils.

McCool (7) and Albrecht (1) concluded that about 500 pounds of fine limestone applied in the row with the legume seeds supported plant growth which was comparable to that secured where larger amounts were used.

Rather than to apply 500 pounds of fine limestone drilled in the row on acid soils regardless of the lime requirement of the soil, it seemed

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[3]Figures in parenthesis refer to "Literature Cited", p. 988.

worthwhile to know whether a relationship exists between the amount of fine limestone to be applied with the seed and the acidity of the soil. A slightly acid soil may not require as much fine limestone drilled with the seed as a more acid soil to insure a good stand of the legume grown.

The object of this investigation was to determine whether it would be desirable when applying small amounts of fine limestone in the row to use an amount which represents a definite proportion of the lime requirement of the soil.

EXPERIMENTAL

Three samples of Tama silt loam from different counties and having lime requirements (4) of 2.2, 3.4, and 4.7 tons, respectively, were secured for this experiment. Only the surface soil was used in this work. The 2.2-ton lime requirement soil had a total nitrogen content of 2,510 pounds per acre; the 3.4-ton lime requirement soil, 2,802 pounds per acre; and the 4.7-ton lime requirement soil, 4,847 pounds per acre. The pH of the 2.2-, 3.4-, and 4.7-ton lime requirement soils was 5.70, 5.12, and 4.87, respectively.

All treatments were made in duplicate and one of each duplicate box was placed in one of two blocks in the greenhouse so that no two similarly treated soils of the same lime requirement were in the same block. The arrangement of each box within the block was determined by a randomization procedure and every 2 weeks the boxes within blocks were rerandomized. Treatments were made of fine limestone in the row at the rates of 1/6, 1/12, and 1/24 of the lime requirement of each of the soils and broadcast to meet the full lime requirement. Alfalfa was the crop selected to be grown. The outline of the treatments for this experiment is shown in Table 1.

TABLE 1.—*Outline of treatments on three samples of Tama silt loam.*

Rate of lime treatment	Method of application	Pounds of limestone applied (acre basis) on soils with lime requirements of		
		2.2 tons*	3.4 tons†	4.7 tons‡
No treatment	—	—	—	—
1/24 lime requirement	In row	183.3	283.3	391.6
1/12 lime requirement	In row	366.6	566.6	783.3
1/6 lime requirement	In row	733.3	1,133.3	1,566.6
Full lime requirement	Broadcast	4,400.0	6,800.0	9,400.0

*Tama silt loam from Guthrie County.
†Tama silt loam from Benton County
‡Tama silt loam from Johnson County

The fine limestone used in this work was 95.5% $CaCO_3$ and 98.5% passed through a 100-mesh screen. The pH determinations were made with a quinhydrone electrode. All the soils, regardless of treatment, received an application of 20% superphosphate at the rate of 200 pounds per surface acre. Twenty-four pounds of air-dry soil were placed in each of 30 boxes which were 12 inches square and 6 inches deep. The alfalfa seeds were placed in rows 4 inches apart. All the seeds were inoculated and the growth in each box thinned down to 30 plants per box. After 120 days of growth, the plants were dug, the roots examined for nodulation, and the tops and roots oven-dried and weighed. The tops and roots were then

ground and the total nitrogen content determined by the Kjeldahl method. An analysis of variance was made of the total nitrogen content and the total dry weight of the plant material.

RESULTS

The height of the alfalfa grown on the three samples of Tama silt loam showing, respectively, a lime requirement of 2.2, 3.4 and 4.7 tons per acre, was determined at definite intervals and the data are recorded in Table 2. Thirty days after planting there was very little difference in the plant growth on the individual soils under the various treatments. The alfalfa grown on the soil having a lime requirement of 4.7 tons per acre was higher, however, than that grown on the other soils with lower lime requirements.

Fifty days after planting, the height of the alfalfa grown on the soil having a 2.2 ton lime requirement, which had received one-twenty-fourth of the lime requirement in the row, was somewhat higher than any of the other treatments of the same soil. The height of the alfalfa grown on the soils requiring 3.4 and 4.7 tons of lime per acre was greatest in both cases where the one-twelfth lime requirement treatment was employed. The one-sixth lime requirement treatment and the full lime requirement treatment broadcast showed a depressive effect on the growth of alfalfa as measured by the height of the plants 64 days after planting. This depressive effect seems to have been overcome 78 days after planting in the one-sixth lime requirement treatment but not until 92 days after planting in the fully limed soils. Sixty-four days after planting there were no striking differences in the height of the alfalfa on any of the soils, irrespective of the reaction or treatment. After this time, however, there was a tendency for the alfalfa to be higher on the soil requiring 2.2 tons of lime per acre and lowest on the soil requiring 4.7 tons per acre.

At the time of harvest the alfalfa was shortest on all three soils where no limestone was applied. There was also a tendency at the time of harvest for the growth of alfalfa to be greatest on the soils receiving the full lime requirement treatment.

pH DETERMINATIONS OF SOILS AT TIME OF HARVEST

The pH values for the soils used in this experiment were determined at the time of harvesting the alfalfa and are found in Table 3. It may be noted that the pH of the soils receiving no limestone has changed but very little during the time of the experiment. There is a general trend for the soils to become more alkaline in the upper 1 inch in the row treatments as the applications of limestone became greater. As indicated by pH, the limestone did not neutralize the soil below the first inch.

YIELD AND NITROGEN CONTENT OF ALFALFA

The yield and nitrogen content of alfalfa grown on the three samples of Tama silt loam having different acidities are given in Tables 4, 5, and 6. The results of an analysis of variance of the total dry weight and total nitrogen content of alfalfa grown on these soils are shown in Table 7.

TABLE 2.—*Height in inches of alfalfa on three samples of Tama silt loam of different initial lime requirement.*

Block	30 days			50 days			64 days			78 days			92 days			106 days			120 days		
	Lime requirement			Lime requirement			Lime requirement			Lime requirement			Lime requirement			Lime requirement			Lime requirement		
	2.2* ton	3.4† ton	4.7‡ ton	2.2 ton	3.4 ton	4.7 ton	2.2 ton	3.4 ton	4.7 ton	2.2 ton	3.4 ton	4.7 ton	2.2 ton	3.4 ton	4.7 ton	2.2 ton	3.4 ton	4.7 ton	2.2 ton	3.4 ton	4.7 ton
No Treatment																					
A	1.0	0.9	1.6	1.8	1.5	1.9	2.5	2.3	2.5	4.5	3.3	3.5	6.3	5.6	5.1	9.8	8.2	6.5	11.2	10.0	9.5
B	1.0	0.9	1.3	1.6	1.3	1.5	2.6	1.7	2.3	4.3	3.0	2.8	7.0	5.6	4.9	9.6	7.5	7.0	11.2	10.2	10.0
Mean	1.0	0.9	1.5	1.7	1.4	1.7	2.6	2.0	2.4	4.4	3.2	3.2	6.7	5.6	5.0	9.7	7.9	6.8	11.2	10.1	9.8
1/24 Lime Requirement in Row																					
A	1.5	1.3	1.4	2.2	1.8	1.6	3.4	2.2	1.9	7.3	3.9	3.2	9.8	6.5	5.3	11.0	9.5	7.5	12.0	12.2	10.2
B	1.4	1.3	1.7	2.0	1.4	1.8	2.4	2.2	2.6	5.8	4.1	4.0	7.3	7.0	7.5	10.3	8.8	9.0	12.0	11.8	11.0
Mean	1.5	1.3	1.6	2.1	1.6	1.7	2.1	2.2	2.3	6.6	4.0	3.6	8.6	6.8	6.4	10.7	9.2	8.3	12.0	12.0	10.6
1/12 Lime Requirement in Row																					
A	1.5	1.0	1.6	1.8	1.5	1.8	2.3	2.0	2.2	4.2	3.7	3.5	8.1	6.0	5.7	9.7	7.8	7.5	13.0	11.2	10.0
B	0.9	1.4	1.6	1.6	1.9	2.0	2.8	2.6	2.8	4.5	4.5	4.0	7.1	6.2	6.8	10.3	9.8	9.0	13.4	12.2	12.0
Mean	1.2	1.2	1.6	1.7	1.7	1.9	2.6	2.3	2.5	4.4	4.1	3.8	7.6	6.1	6.3	10.0	8.8	8.3	13.2	11.7	11.0
1/6 Lime Requirement in Row																					
A	0.9	1.1	1.4	1.6	1.4	1.8	2.1	1.5	2.3	4.0	2.5	3.4	6.7	5.5	4.7	8.8	7.3	7.0	11.2	12.2	9.0
B	1.1	1.3	1.4	1.8	1.6	1.6	2.8	2.5	2.3	5.0	4.3	3.8	8.7	6.7	6.2	11.0	9.6	9.0	13.0	11.2	11.0
Mean	1.0	1.2	1.4	1.7	1.5	1.7	2.5	2.0	2.3	4.5	3.4	3.6	7.7	6.1	5.5	9.9	8.5	8.0	12.1	11.7	10.0
Full Lime Requirement Broadcast																					
A	1.0	1.0	1.5	1.5	1.6	1.5	2.2	2.2	2.3	3.7	3.7	4.0	7.3	6.0	6.1	10.6	9.3	9.3	13.0	13.0	12.0
B	1.2	0.8	1.7	1.5	1.2	1.9	2.4	2.0	2.3	4.2	3.5	4.8	7.7	5.8	7.3	10.0	9.2	10.6	13.8	13.2	13.0
Mean	1.1	0.9	1.6	1.5	1.4	1.7	2.3	2.1	2.3	4.0	3.6	4.4	7.5	5.9	7.6	10.3	9.3	10.0	13.4	13.1	12.5

*Tama silt loam from Guthrie County.
†Tama silt loam from Benton County.
‡Tama silt loam from Johnson County.

TABLE 3.—*The pH of soils at time of harvesting alfalfa on Tama silt loam of different initial lime requirements.**

Region of sampling	Block	Lime requirement 2.2 ton		Lime requirement 3.4 ton		Lime requirement 4.7 ton	
		pH	Mean	pH	Mean	pH	Mean
			No Treatment				
In the row . .	A	5.66	—	5.09	—	4.80	—
0 to 1 in. deep	B	5.67	5.67	5.13	5.11	4.86	4.83
In the row. . .	A	5.70	—	5.13	—	4.88	—
1 to 2 in. deep	B	5.70	5.70	5.07	5.10	4.81	4.85
			1/24 Lime Requirement in Row				
In the row . .	A	6.14	—	5.69	—	5.58	—
0 to 1 in. deep	B	6.00	6.07	5.77	5.73	5.68	5.63
In the row . .	A	5.64	—	5.16	—	4.99	—
1 to 2 in. deep	B	5.62	5.63	5.10	5.13	4.93	4.96
			1/12 Lime Requirement in Row				
In the row	A	6.24	—	5.75	—	6.18	—
0 to 1 in. deep	B	6.24	6.24	5.63	5.69	6.14	6.15
In the row .	A	5.68	—	5.13	—	4.96	—
1 to 2 in. deep	B	5.62	5.65	5.03	5.08	4.88	4.92
			1/6 Lime Requirement in Row				
In the row. . .	A	6.65	—	6.39	—	6.38	—
0 to 1 in. deep	B	6.52	6.59	6.43	6.41	6.48	6.43
In the row. . .	A	5.63	—	5.10	—	5.04	—
1 to 2 in. deep	B	5.67	5.65	5.04	5.07	5.00	5.02
			Full Lime Requirement Broadcast				
In the row. . .	A	7.33	—	7.00	—	7.28	—
0 to 1 in. deep	B	7.27	7.30	6.94	6.97	7.18	7.23
In the row. .	A	7.30	—	6.77		7.26	—
1 to 2 in. deep	B	7.20	7.25	6.87	6.82	7.12	7.19

*At the beginning of the experiment the 2.2 ton lime requirement soil had a pH of 5.70, the 3.4 ton lime requirement soil a pH of 5.12, while the 4.7 ton lime requirement soil had a pH of 4.87.

The plant growth in three boxes was greatly decreased as a result of infection by the "damping-off" organism. In order to make a statistical analysis of the data in this experiment, these three values were calculated according to statistical methods used for the calculation of missing pots.

The statistical analysis shows that there was a highly significant difference in the total yield and total nitrogen content of the alfalfa which was grown on the three soils. The total dry weight and total nitrogen content were highly significantly less for the alfalfa grown on untreated soils than for that grown on the soils receiving limestone applied in the row. The fully limed soils gave greater yields and the plants contained more nitrogen than when grown on the soils where

TABLE 4.—*The yield and nitrogen content of alfalfa on Tama silt loam having 2.2 tons lime requirement.*

Block	Tops			Roots			Total plant	
	Dry weight, grams*	Nitrogen, %	Total nitrogen, mgms	Dry weight, grams*	Nitrogen, %	Total nitrogen, mgms	Dry weight, grams*	Total nitrogen, mgms
				No Treatment				
A	8.0	3.23	259.2	4.0	1.66	66.8	12.0	326.0
B	7.0	3.14	220.5	4.8	1.60	76.8	11.8	297.3
Mean	7.5	3.19	239.8	4.4	1.63	71.8	11.9	311.6
				1/24 Lime Requirement in Row				
A	7.7	3.03	237 2	7.6	1.63	213.9	15.3	361.1
B	8.6	3.16	271.8	6.0	1.62	97.2	14 6	369.0
Mean	8.2	3.12	254.5	6.8	1.63	110.5	15.0	365.0
				1/12 Lime Requirement in Row				
A	8.0	3.12	250.4	5.6	1.77	99.7	13.6	350.1
B	9 2	3.23	297.2	5.0	1.87	93.5	14.2	390.7
Mean	8.6	3.18	273.8	5.3	1.82	96.6	13.9	370.4
				1/6 Lime Requirement in Row				
A	7.8	3.59	280 0	5.3	1.90	100.7	13.1	380.7
B	8.7	3.48	302.8	5.1	1.91	97.4	13.8	400.2
Mean	8 3	3.44	291.4	5.2	1.91	99.1	13.5	390.5
				Full Lime Requirement Broadcast				
A	10.6	3.54	375.2	4.8	2.22	107.0	15.4	482.2
B	11.0	3.43	377.3	5.2	2.11	109.7	16.2	487.0
Mean	10.8	3.49	376.2	5.0	2.17	108.3	15.8	484.6

*Oven-dry weight (5% moisture).

the limestone was applied in the row. These differences were found to be highly significant. There was no significant difference between the dry weight or nitrogen content of the alfalfa grown on the soils receiving the addition of lime at the rate of one-twelfth of the lime requirement and that grown on the soils receiving lime at the rate of one-sixth of the lime requirement.

TAMA SILT LOAM HAVING A 2.2-TON LIME REQUIREMENT

According to the results given in Table 4, the soil receiving lime at the rate of one-twelfth of the lime requirement yielded more alfalfa (tops) than those receiving lime at the rates of one-sixth or one-twenty-fourth of the lime requirements applied in the row.

There was very little difference in the percentage nitrogen of the alfalfa tops grown on the untreated soils, on those receiving lime at the rate of one-twenty-fourth of the lime requirement, or on those receiving one-twelfth of the lime requirement. The percentage nitro-

TABLE 5.—*The yield and nitrogen content of alfalfa on Tama silt loam having 3.4 tons lime requirement.*

Block	Tops			Roots			Total plant	
	Dry weight, grams*	Nitrogen, %	Total nitrogen, mgms	Dry weight, grams*	Nitrogen, %	Total nitrogen, mgms	Dry weight, grams*	Total nitrogen, mgms
				No Treatment				
A	5.4	3.24	175.0	3.6	1.75	63.0	9.0	238.0
B	5.3	3.14	166.4	2.6	1.66	43.2	7.9	209.6
Mean	5.4	3.19	170.7	3.1	1.71	53.1	8.5	223.8
				1/24 Lime Requirement in Row				
A	7.6	3.30	250.8	5.1	1.70	86.4	12.7	337.5
B	6.8	3.20	217.6	4.6	1.70	78.2	11.4	295.8
Mean	7.2	3.26	234.2	4.9	1.70	82.4	12.1	316.6
				1/12 Lime Requirement in Row				
A	7.1	3.55	252.8	5.0	1.73	86.5	12.1	339.3
B	8.3	3.41	283.0	7.3	1.85	135.0	15.6	418.0
Mean	7.7	3.49	267.9	6.2	1.79	110.7	13.9	378.6
				1/6 Lime Requirement in Row				
A	—†	—	—	—†	—	—	(13.5)‡	(337.3)‡
B	8.0	3.40	272.0	5.6	2.09	117.6	13.6	389.6
Mean	8.0	3.40	272.0	5.6	2.09	117.6	(13.55)‡	(362.05)‡
				Full Lime Requirement Broadcast				
A	9.8	3.90	382.2	5.7	2.23	127.1	15.5	509.3
B	8.3	4.14	344.5	4.8	2.28	109.4	13.1	453.9
Mean	9.1	4.03	363.3	5.3	2.26	118.2	14.3	481.6

*Oven-dry weight (5% moisture).
†Plant growth ruined by disease.
‡The numbers in parenthesis are the values calculated by statistical methods.

gen of the plants grown on the soil where lime was added at the rate of one-sixth of the lime requirement, however, was very nearly the same as in the case of the plants grown on the fully limed soils. These latter plants contained a higher percentage of nitrogen than those grown on any of the other soils. The same general trend in percentage nitrogen content noted in the results of the alfalfa tops was found also in the case of the roots.

The dry weight of the alfalfa roots was the greatest in the soil receiving lime at the rate of one-twenty-fourth of the lime requirement, and it was the smallest on the soils receiving no treatment. The roots of the plants were all well inoculated, irrespective of the treatment; however, the roots of the plants grown on the soils receiving lime at the rate of one-sixth of the lime requirement showed a tendency toward a concentration of nodules in the row where the fine limestone had been applied. A larger number of nodules was observed

TABLE 6.—*The yield and nitrogen content of alfalfa on Tama silt loam having 4.7 tons lime requirement.*

Block	Tops			Roots			Total plant	
	Dry weight, grams*	Nitrogen, %	Total nitrogen, mgms	Dry weight, grams*	Nitrogen, %	Total nitrogen, mgms	Dry weight, grams*	Total nitrogen, mgms
				No Treatment				
A	4.7	3.28	154.6	3.0	1.86	45.8	7.7	200.4
B	4.0	3.38	135.6	2.5	1.93	48.3	6.5	183.9
Mean	4.4	3.34	145.1	2.8	1.90	47.0	7.1	192.1
				1/24 Lime Requirement in Row				
A	5.3	3.56	188.7	3.7	1.83	68.5	9.0	257.2
B	6.6	3.46	229.0	4.9	1.81	88.7	11.5	317.7
Mean	6.0	3.62	208.0	4.3	1.82	78.6	10.3	287.4
				1/12 Lime Requirement in Row				
A	—†	—	—	—†	—	—	(10.9)‡	(294.0)‡
B	7.4	3.64	269.4	4.0	1.92	76.8	11.4	346.2
Mean	7.4	3.64	269.4	4.0	1.92	76.8	(11.15)‡	(320.1)‡
				1/6 Lime Requirement in Row				
A	—†	—	—	—†	—	—	(11.1)‡	(309.2)‡
B	6.6	3.66	242.2	4.6	1.93	88.8	11.2	331.0
Mean	6.6	3.66	242.2	4.6	1.93	88.8	(11.15)‡	(320.1)‡
				Full Lime Requirement Broadcast				
A	7.8	3.70	288.6	6.0	2.07	124.8	13.8	413.4
B	8.6	3.66	315.6	6.3	2.16	136.1	14.9	451.7
Mean	8.2	3.69	302.1	6.2	2.12	130.4	14.4	432.5

*Oven-dry weight (5% moisture).
†Plant growth ruined by disease
‡The numbers in parenthesis are the values calculated by statistical methods

on the roots of the plants grown on the fully limed soil than on any of the other soils.

The total nitrogen content of alfalfa grown on this soil became greater as the applications of limestone increased.

THE TAMA SILT LOAM HAVING A 3.4-TON LIME REQUIREMENT

It may be observed in Table 5 that where fine limestone was applied in the row, the treatment at the rate of one-twelfth of the lime requirement gave the largest total growth of alfalfa. If the calculated value for the growth secured on the one-sixth lime requirement treatment, which may be found in parenthesis in the table, were used, the growth would appear to be very nearly the same as that secured on soils receiving lime at the rate of one-twelfth of the lime requirement.

The percentage nitrogen of the tops of alfalfa grown on this soil increased as the applications of limestone increased.

TABLE 7.—*Analysis of variance of total dry weight and total nitrogen content of alfalfa grown on three samples of Tama silt loam of different initial lime requirements.*

Source of variation	Degrees of freedom	Mean square	
		Dry weight	Total N
Between blocks	1	.32	1,413.2
Between soils	2	25.60**	13,771.7**
Between treatment†			
L_2-L_3	1	.18	7.84
$2L_1$-L_2-L_3	1	.72	4,662.6**
$3L_0$-L_1-L_2-L_3	1	56.71**	47,998.3**
$4L_4$-L_1-L_2-L_3-L_0	1	42.84**	102,679.2**
Treatment × soil	8	2.01	600.4
Error	14	1.10	944.9
Total	29	6.33	6,977.1
$2L_4$-L_2-L_3	1	15.34**	47,574.8**

**Highly significant.
†L_0 = No treatment L_1 = 1/24 lime requirement in row L_2 = 1/12 lime requirement in row. L_3 = 1/6 lime requirement in row. L_4 = Full lime requirement broadcast.

There was very little difference in the percentage nitrogen of the alfalfa roots grown on the untreated soil, on that receiving lime at the rate of one-twenty-fourth of the lime requirement, and on that receiving the treatment at the rate of one-twelfth of the lime requirement. The percentage nitrogen of the alfalfa roots grown on the soils on which lime was added at the rate of one-sixth of the lime requirement and that of the roots in the case of the fully limed soils were practically the same.

About 60% of the roots of the alfalfa plants grown on the untreated soil were inoculated. An estimate of about five nodules per plant was made for the roots that were inoculated. The roots of the plants grown on the soil receiving lime at the rate of one-twenty-fourth of the lime requirement were about 90% inoculated, whereas, in the case of the plants on soils receiving larger amounts of limestone, the roots were 100% inoculated.

A distinct concentration of nodules on the alfalfa roots could be observed in the limed zone where the treatments were made at the rate of one-twelfth and one-sixth of the lime requirements. The nodules were distributed over the entire root system where the alfalfa was grown on the fully limed soils.

The total dry weight of the alfalfa grown on the soil receiving lime at the rate of one-twelfth of the lime requirement was very nearly the same as that obtained on the fully limed soil. The plants grown on the soil receiving lime at the rate of one-twelfth of the lime requirement contained more nitrogen than that grown on any of the other treated soils, with the exception of the fully limed soil. Had the plant growth not been disrupted by disease on the soil receiving the one-sixth lime requirement treatment, the results probably might have been different.

THE TAMA SILT LOAM HAVING A 4.7-TON LIME REQUIREMENT

The soil in two of the boxes was badly infected with a "damping-off" organism which retarded the plant growth in these boxes. The numbers found in parenthesis in Table 6 are the values calculated by statistical methods and these values will be employed in drawing the conclusions.

The percentage nitrogen of the alfalfa tops grown on the untreated soils was much lower than in the case of plants grown on the soils receiving limestone. In the alfalfa grown on the soils receiving treatments with limestone, there was very little difference in the percentage nitrogen content. The plants grown on the soils receiving the lime treatment at the rate of one-sixth of the lime requirement, however, did show the highest percentage content of nitrogen. This may have been due in part to the retarded plant growth on one of the soils as smaller plants often contain a higher percentage of nitrogen than larger plants.

The total dry weight of alfalfa grown on the untreated soils was less than one-half of that secured on the fully limed soil. The larger lime applications in the row appear to be more favorable to the growth of alfalfa than the smaller amounts. These yields were somewhat less, however, than those secured on the fully limed soil.

The plants on the soils receiving lime at the rate of one-sixth and one-twelfth of the lime requirement contained more nitrogen than those grown on the soil receiving the treatment at the rate of one-twenty-fourth of the lime requirement. The total nitrogen content of the plants grown on the soils receiving limestone in the row was about half way between that of the plants grown on the untreated soil and that of the alfalfa grown on fully limed soil

Comparing the data in Tables 4, 5, and 6, it appears that, in general, the total dry weight and total nitrogen content of the alfalfa grown on Tama silt loam with a 2 2-ton lime requirement was greater than in the case of the alfalfa grown on the other two soils. The soil having the 4.7-ton lime requirement gave the smallest yields with the lowest total nitrogen content of the three soils studied. This was especially true of the plants grown on the untreated soils. The difference was not so noticeable where the soils were fully limed, however, except in case of the soil having the 4.7-ton lime requirement.

The interaction (treatment × soil) given in Table 7 indicated that the plants responded similarly on the different soils to equivalent treatments.

In general, the experimental results and the statistical analyses show that the nitrogen content of the plants increased with increasing applications of limestone. The growth of the plants showed a similar, though less pronounced, trend.

SUMMARY AND CONCLUSIONS

Three samples of Tama silt loam having a lime requirement of 2.2, 3.4, and 4.7 tons per acre, respectively, were selected for a greenhouse study of the effects of various amounts of fine limestone applied in the row upon the growth and nitrogen content of alfalfa. The plants

were harvested at the stage of inflorescence, oven-dried, weighed, and analyzed statistically according to the method of analysis of variance. The results obtained may be summarized as follows:

1. Limestone did not depress the early growth of alfalfa on the 3.4- and 4.7-ton lime requirement soils. Early growth was retarded, however, on the 2.2-ton lime requirement soil.

2. The fully limed soils produced highly significantly greater yields of alfalfa than the soils receiving limestone in the row. The nitrogen content of the plants grown on the fully limed soils was greater than on soils which received limestone in the row.

3. The total dry weight and total nitrogen content of alfalfa grown on untreated soils were highly significantly less than those secured on soils receiving limestone.

4. In general, the 2.2-ton lime requirement soils produced larger yields and greater nitrogen content of alfalfa than either the 3.4- or 4.7-ton lime requirement soils. The 4.7-ton lime requirement soil gave the smallest yield of alfalfa.

5. The data show that there was no difference in the crop yield and nitrogen content of alfalfa grown on soils receiving the one-twelfth lime requirement treatment and that grown on the same soil receiving the one-sixth lime requirement treatment.

6. The percentage nitrogen content of the tops and roots of the plants responded similarly to the various limestone treatments.

7. A greater number of nodules were present on the roots of plants grown on fully limed soils than on those grown on the soils which received limestone applications in the row.

8. A distinct concentration of nodules on the alfalfa roots was found in the limed zone where larger amounts of fine limestone were applied in the row.

9. The interaction (treatment × soil) showed that the plants responded similarly to equivalent treatments on soils having different lime requirements. This would seem to indicate that there is no relation between the lime requirement of a soil and the amount of fine limestone that should be applied in the row.

10. The total nitrogen content of alfalfa increased as the applications of fine limestone in the row increased. It seems logical to conclude, therefore, that only as the full lime requirement of a soil is approached would nitrogen fixation equal to that secured on the fully limed soils be obtained.

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EFFECT OF FERTILIZATION ON THE COMPOSITION OF A LUFKIN FINE SANDY LOAM AND OF OATS GROWN ON IT[1]

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AN experiment to study the effect of fertilization on the yield of cotton, corn, and oats grown in rotation on a Lufkin fine sandy loam at College Station, Texas, was started by the Division of Agronomy of the Texas Agricultural Experiment Station in 1927. After 8 years, it seemed desirable to determine what differences the continued fertilization over the 8-year period had brought about in the composition of the soil of the plats differently treated. Results of the study are reported in this paper.

PLAN OF THE EXPERIMENT

A 3-year rotation of cotton, corn, and oats was used, the oats being grown in the winter following corn. The experiment was started with cotton in 1927. The plats were 1/22 acre in size, consisting of 5 rows, 132 feet long, and each treatment was replicated four times. The first and last rows of each plat served as border or guard rows; the crops from these rows were discarded at harvest time. Fertilizers of varying formulae and amounts were applied to the different series. The fertilizers were made from sulfate of ammonia, superphosphate, and muriate of potash. The effects of the fertilizers on the yield of cotton over a 5-year period have been discussed by Reynolds (3)[3].

Samples of soil from 44 of the plats (11 out of 22 treatments) were collected in November, 1935. Borings with a soil augur were made in the section of the plats used for securing yields. About 40 borings were taken in each plat at equidistant spots and composited. The surface soil was taken to a depth of 6 inches, the depth to which the soil was stirred in plowing, and the subsoil was taken from 6 to 12 inches. The surface soil was a fairly uniform fine sandy loam. The subsoil was a heavy, semi-impervious clay, encountered at an average depth of about 8.5 inches, although the depth to the clay varied at different points in the plats. Total nitrogen, active (N/5 nitric acid-soluble) phosphoric acid and potash (1,2), and pH were determined in samples of surface soil and subsoil from each plat. Since the composition of the samples of soil from the four replications of each treatment did not differ greatly, only the average composition of the samples is given in the tables.

In order to study the relation between the quantities of nutrients in the soil and those in the crop grown on the soil, samples of oats were secured February 12, 1936, and April 27, 1936. The oats were just beginning to tiller vigorously in February, while in April they were beginning to mature, with the grain in the soft dough stage. Samples of the oats were secured from each of the 44 plats. Composite samples made for each of the four plats receiving the same treatment were analyzed for nitrogen, phosphoric acid, and potash. Fertilizers for the oats had

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[3]Figures in parenthesis refer to "Literature Cited", p. 996.

been applied between the time the samples of soil were secured and the time the samples of oats were taken.

RESULTS

The fertilizer treatments for the different series and the total yields of cotton, corn, and oats over the 8-year period are given in condensed form in Table 1. Three crops of cotton, three of corn, and one of oats were produced; the crop of oats in 1933 was completely destroyed by winterkilling. Cotton responded to the addition of phosphoric acid and potash (3), but the results with corn and oats were not so definite.

TABLE 1.—*Fertilizer treatments and total yields of cotton (3 crops), corn (3 crops), and oats (1 crop).*

Series No.	Fertilizer applied		Lint cotton, lbs.	Corn, bu.	Oats (1930)	
	Formula	Pounds per acre per year			Straw, lbs.	Grain, bu.
1	0	0	704	81.4	2,132	33.3
2	0-12-4	400	880	95.3	2,045	36.0
3	4-12-4	400	916	90.0	2,068	36.4
4	8-12-4	400	853	93.5	2,738	31.6
5	4-12-4	800	967	94.1	2,211	35.5
6	8-12-8	800	907	85.8	2,437	37.6
7	4-0-4	400	814	87.5	2,756	39.6
8	4-8-4	400	930	98.5	2,074	36.2
9	4-12-0	400	764	95.1	1,696	32.9
10	Manure	12 tons	982	100.6	2,282	43.7
11	Manure Superphosphate	12 tons 400	1,080	103.5	2,438	32.7

The quantities of total nitrogen, active phosphoric acid, and active potash found in the soil samples are given in Table 2. The increases over the check plats due to fertilization, expressed as percentages of those constituents found in the check plats and as percentages of the total quantities added to the soil, are given in Table 3. Although the increase in percentages of nitrogen was small, 50 to 70% of the nitrogen added was found in the surface 0 to 6 inches (Table 3).

The application of fertilizer increased the active phosphoric acid greatly in both the surface soil and the subsoil (Table 2). From 36 to 48% of the phosphoric acid added in the fertilizers was found in the top layer of the soil in compounds which were soluble in N/5 nitric acid. On the average, the plats that received phosphoric acid contained 165 p. p. m. in the top soil, or 3.68 times as much as the plats which received no phosphoric acid.

Reynolds (4) in some previous work on the same soil obtained similar results; the plats treated with phosphoric acid contained on the average 121 p. p. m., or 2.57 times as much as the soil which received no phosphoric acid. In this case, however, much smaller amounts of phosphoric acid were applied to the soil.

Altho the larger increases occurred in the surface soil, the increases in the subsoil show that there was an appreciable downward pene-

TABLE 2.—*Relation of fertilizers to nitrogen, active phosphoric acid, and active potash in the soil.*

Series No.	Total nutrients added, lbs. per acre			Nutrients found in soil					
				Nitrogen		Active phosphoric acid		Active potash	
	Nitrogen	Phosphoric acid	Potash	0–6 in., %	6–12 in., %	0–6 in., p.p.m.	6–12 in., p.p.m.	0–6 in., p.p.m.	6–12 in., p.p.m.
1	0	0	0	0.047	0.054	38	18	37	38
2	0	384	128	0.054	0.060	173	43	53	46
3	128	384	128	0.054	0.059	109	30	46	40
4	256	384	128	0.054	0.057	126	35	60	41
5	256	768	256	0.060	0.059	258	71	95	64
6	512	768	512	0.064	0.064	246	60	109	68
7	128	0	128	0.057	0.061	43	17	59	51
8	128	256	128	0.052	0.060	92	26	60	55
9	128	384	0	0.059	0.062	128	34	49	51
10	960*	336*	960*	0.077	0.067	108	32	141	72
11	960*	976*	960*	0.080	0.063	249	73	136	76

*Estimated.

TABLE 3.—*Average relation of additions of nitrogen, phosphoric acid, and potash to these constituents found in the soil.*

Constituents	Total pounds added	Series Nos.	Found in soil as percentage of checks		Increase as percentage of additions		
			0–6 in.	6–12 in.	0–6 in.	6–12 in.	Total
Nitrogen	128	3, 7, 8, 9	110	105	70	39	109
Nitrogen	256	4, 5	114	102	50	7	57
Nitrogen	512	6	128	112	50	24	74
Active phosphoric acid	256	8	230	144	36	6	42
Active phosphoric acid	384	2, 3, 4, 9	335	200	36	8	44
Active phosphoric acid	768	5, 6	630	361	48	11	59
Active potash	128	2, 3, 4, 7, 8	130	107	18	3	21
Active potash	256	5	221	145	36	13	49
Active potash	512	6	253	154	22	9	31

tration of the phosphoric acid of the fertilizer. For example, the subsoil in the plats which received no phosphoric acid contained about 18 p. p. m. of active phosphoric acid as compared with 45 p. p. m. on the plats that received phosphoric acid.

Increases in active potash over the check plats were large in both the surface soil and the subsoil, altho not as great as the increases in active phosphoric acid. From 18 to 36% of the potash in the fertilizer was found as active potash in the top soil and 3 to 13% in the subsoil (Table 3). This shows an appreciable downward movement of the potash into the subsoil.

In order to secure further information concerning the nature of the compounds in which the increase in active potash occurred, the exchangeable potash was determined in the soil from four series to

which had been added different amounts of potash. The exchangeable potash was first removed by leaching with neutral, normal ammonium acetate; then the washed soil residue was digested with N/5 nitric acid, as in the determination of active potash. The figures secured (Table 4) show that all of the differences in active potash due to the addition of fertilizer were caused by increases in exchangeable potash, and practically no differences are found in the active potash present after the exchangeable potash had been removed. Possibly some of the potash from the fertilizer went into compounds which would have been soluble in stronger acid, but Fraps (1, 2) has shown that the active potash is that fraction of the soil potash most intimately related to the quantities of potash removed by crops.

TABLE 4.—*Relation of potash fertilization to active and exchangeable potash in the soil.*

	Series No.			
	9	3	5	6
Total potash added, pounds per acre	0	128	256	512
Potash in surface soil, p.p.m.:				
Active	49	46	95	109
Exchangeable	62	58	104	119
Active after ammonium acetate leaching	14	15	15	18
Potash in subsoil, p.p.m.:				
Active	34	30	71	60
Exchangeable	55	58	78	80
Active after ammonium acetate leaching	9	12	15	10

Manure (Table 2) increased the total nitrogen in the surface soil significantly but had little, if any, effect upon the nitrogen in the subsoil. It increased active phosphoric acid by an amount intermediate between the increases caused by 256 and 384 pounds of phosphoric acid in the commercial fertilizers The active potash in the surface soil receiving manure (series 10 and 11) was approximately 28% greater than in series 9 which received 512 pounds of potash in commercial fertilizer; that in the subsoil was about 9% greater

Differences in soil acidity due to addition of the fertilizers were ascertained by determining the pH of the soil in three conditions, *viz.*, as it came from the field, after it had been washed to free the soil from soluble salts, and in normal potassium chloride solution Exchangeable hydrogen was determined after leaching with neutral normal ammonium acetate and by titrating the hydrogen in the leachate (5). Results of this work are given in Table 5.

The effect of additions of phosphoric acid upon soil acidity is shown by comparing the figures for series 7, 8, and 3, which received the same quantities of nitrogen but increasing quantities of phosphoric acid. The pH values of the natural soil (5.61, 5.54, 5.47) were slightly different, but the pH of the washed soil and the soil in potassium chloride was practically the same. The differences in pH values of the natural soils probably are due to different quantities of soluble salts. The conclusion may safely be made, therefore, that the phosphoric acid fertilization had practically no effect on soil acidity.

TABLE 5.—*Relation of fertilizers on acidity of surface soil.*

Fertilizers	Series No.	pH values			Exchangeable hydrogen, m. e.
		As taken	Washed soil	Potassium chloride	
0	1	5.79	6.47	4.87	1.90
0-12-4	2	5.44	5.98	4.79	2.25
4-12-4	3	5.47	6.27	4.70	2.66
8-12-4	4	5.05	5.67	4.30	2.84
4-12-4	5	5.00	5.55	4.43	2.92
8-12-8	6	5.16	5.72	4.59	2.83
4-0-4	7	5.61	6.00	4.69	2.53
4-8-4	8	5.54	5.92	4.56	2.48
4-12-0	9	5.71	6.04	4.70	2.62
Manure	10	6.44	6.81	5.69	1.65
Manure and superphosphate	11	6.24	6.66	5.53	1.93

Addition of potash (compare series 9 and 3) apparently increased soil acidity, if the pH values of the natural soil alone are considered, but all the other figures indicate that there were no significant differences in acidity.

Nitrogen increased the acidity in most of the plats; manure decreased it considerably.

RELATION BETWEEN COMPOSITION OF SOILS AND OF OATS GROWN ON THEM

The quantities of nitrogen, phosphoric acid, and potash in the samples of oats collected on February 12 and on April 27, 1936, are shown in Table 6, with the plats arranged in order of increasing quantity of the corresponding constituent in the soil. Nitrogen in the oats collected on February 12 increased from 2.08% in series 2 (400 pounds of 0-12-4) to 3.15% in series 6 (800 pounds of 8-12-8). Although the quantity of total nitrogen in the soils of series 10 and 11, which received manure, was considerably greater than that in series 6, the quantity of nitrogen in the oats was considerably less, indicating that a greater portion of the total nitrogen was not available for plant nutrition. On April 27, the percentage of nitrogen in the oats had decreased to just about one-half of what it had been on February 12 and the differences between the plats had nearly disappeared, altho the oats from plats receiving large quantities of nitrogen still contained larger quantities than the oats from plats receiving the smaller quantities.

The phosphoric acid content of oats collected February 12 was higher with increased quantities of active phosphoric acid in the soil, but when the active phosphoric acid exceeded 100 p. p. m., further increases in the soil were not accompanied by significantly larger percentages of phosphoric acid in the oats. Differences in the phosphoric acid content of the oats collected on April 27 were not regular either with respect to active phosphoric acid in the soil or to the total quantity of phosphoric acid added to the soil in fertilizers.

The potash content of the oats showed considerable variation at both dates of sampling. Though the differences were not regular, there was a tendency for higher percentages of potash in the oats to accompany higher quantities of potash in the soil.

The figures in Table 6 indicate a relation between the quantity of constituent in the plant and the quantity in the soil, particularly with respect to nitrogen and phosphoric acid so long as the oats were in a vegetative stage of growth, but the relation was less clear as maturity approached.

TABLE 6.—*Relation between nitrogen, active phosphoric acid, and active potash in the soil and the composition of oats on February 12 and April 27.*

Nitrogen				Phosphoric acid				Potash			
Series No.	In surface soil, %	In oats 2/12 %	In oats 4/27 %	Series No.	In surface soil, p.p.m.	In oats 2/12 %	In oats 4/27 %	Series No.	In surface soil, p.p.m.	In oats 2/12 %	In oats 4/27 %
1	0.047	2.35	1.16	1	38	0.62	0.95	1	37	1.31	0.95
8	0.052	2.37	1.27	7	43	0.48	0.77	3	46	1.23	0.87
2	0.054	2.08	1.11	8	92	0.74	0.96	9	49	1.33	0.85
3	0.054	2.17	1.11	10	108	0.88	1.26	2	53	1.26	0.82
4	0.054	2.52	1.22	3	109	0.94	0.87	7	59	1.47	0.77
7	0.057	2.42	1.23	4	126	1.13	0.77	8	60	1.50	0.96
9	0.059	2.37	1.21	9	128	0.85	0.85	4	60	1.63	0.77
5	0.060	2.49	1.36	2	173	0.93	0.82	5	95	1.28	1.12
6	0.064	3.15	1.57	6	246	0.93	0.78	6	109	1.84	0.78
10	0.077	2.65	1.31	11	249	1.27	1.11	11	136	2.17	1.11
11	0.080	2.53	1.10	5	258	0.90	1.12	10	141	1.74	1.26

Reynolds (4) found that the total nitrogen, total phosphoric acid, and active phosphoric acid are correlated with the ability of the soil to furnish nitrogen to plants. The nitrifying capacity of the soil, however, was a better index to the crop-producing power of the soil than the total nitrogen, the total phosphoric acid, or the active phosphoric acid of the soil.

SUMMARY

A study was made of the effect of fertilizers added during a period of 8 years in varying quantities up to a maximum of 800 pounds of an 8-12-8 fertilizer per acre, on the quantities of nitrogen, active phosphoric acid, active potash, and acidity in Lufkin fine sandy loam soil, and of the relation of these to the composition of oats grown on the soil at College Station, Texas.

Of the total amount of nitrogen added, 50 to 70% was found in the surface 6 inches of soil; only a small amount had penetrated into the subsoil. From 36 to 48% of the phosphoric acid added was found as active phosphoric acid in the surface 6 inches of soil. The phosphoric acid penetrated to a considerable depth as shown by the fact that the subsoil of the plats that received phosphoric acid contained about 2½ times as much active phosphoric acid as the plats which received no phosphoric acid. Practically all of the increases in active

potash were caused by increases in exchangeable potash. Potash also penetrated the subsoil, but to a lesser extent than phosphoric acid.

Additions of phosphoric acid and potash had little, if any, effect on soil acidity, but nitrogen added as sulfate of ammonia increased acidity; manure decreased it.

The phosphoric acid and nitrogen contents of the oats were fairly well related to the quantity of these constituents in the soil while the oats were in a vegetative stage of growth, but the relation was not close in oats cut near maturity. The relation with respect to potash was irregular at both stages of growth.

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INHERITANCE OF RESISTANCE TO LOOSE AND COVERED SMUTS IN OAT HYBRIDS[1]

GEORGE M. REED AND T. R. STANTON[2]

RESULTS on the inheritance of smut resistance in crosses between Markton and certain other oat varieties were reported in a previous paper.[3] Markton is very resistant to the specialized races of both loose smut (*Ustilago avenae* (Pers.) Jens.) and covered smut (*U. levis* (K. and S.) Magn.), that have been used by the senior author in his experiments. Of the other varieties used as parents, Canadian, Early Champion, and Victor are susceptible to both smuts, Gothland is susceptible to loose smut but resistant to covered smut, while Monarch is resistant to loose smut and susceptible to covered smut.

Results with eight additional hybrids are presented in the present paper. These may be classified into three groups, based on the reaction of the parental varieties to the specific physiologic races of the loose and covered smuts.

MATERIALS AND METHODS

Group 1 involved crosses of the variety Victor, susceptible to both smuts, with Seizure and Scottish Chief susceptible to loose smut but resistant to covered smut.

Group 2 involved crosses of five varieties susceptible to loose smut and resistant to covered smut with Monarch, which is susceptible to covered smut but resistant to loose smut. These five varieties crossed with Monarch are Gothland, Rossman, Danish, Seizure, and Scottish Chief.

Group 3 consisted only of the Danish Island×Monarch cross. Danish Island is very susceptible to loose smut and but slightly susceptible to covered smut.

The history of these crosses is the same as for those reported in the previous paper,[4] and the specialized races of the smuts and methods of inoculation are identical. Data were obtained for the F_2, F_3, and F_4, and, in some cases, on the F_5 generations, but those for the F_4 and F_5 generations are omitted in this paper.

EXPERIMENTAL DATA

The data for the parental varieties and those obtained for the F_2 generation are given in Table 1. The parental varieties, Danish, Danish Island, Gothland, Rossman, Seizure, and Victor, have shown from 89.9 to 96.0% infection with loose smut. Scottish Chief has not shown so high a degree of susceptibility, as only an average of 55.5% of infection with loose smut was obtained. An infection above 75% has never been secured in the many experiments with Scottish Chief. Monarch, on the other hand, has shown a high degree of resistance to this smut, and only 0.4% of the inoculated plants were infected.

[1]The investigations reported herein were conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Brooklyn Botanic Garden, Brooklyn, N. Y. Brooklyn Botanic Garden Contribution No. 81. Received for publication September 30, 1937.

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[3]REED, G. M., and STANTON, T. R. Inheritance of resistance to loose and covered smut in Markton oat hybrids. In press in Jour. Agr. Res.

[4]See footnote 3.

Seizure, Gothland, Rossman, and Danish have not been infected with covered smut. Only 2 plants out of a total of 276 of Scottish Chief were infected, while Danish Island has given 8.4% of infection. Victor and Monarch show an average covered smut infection of 95.1 and 96.1%, respectively.

The data for the F_3 progenies are recorded in Table 2, where the progenies are grouped into 12 infection classes. However, for convenience of discussion, they are further grouped empirically into three classes, namely, resistant, segregating, and susceptible. Progenies having no smut were considered resistant, those having 50% or more of smut were classed as susceptible, and the remaining progenies were classed as segregating.

Three sets of F_3 progenies were grown, depending upon the treatment of the F_2 parent, as follows: (a) F_3 progenies descended from uninoculated F_2 plants; (b) F_3 progenies descended from F_2 plants inoculated with loose smut; and (c) F_3 progenies descended from F_2 plants inoculated with covered smut.

RESULTS OBTAINED

HYBRIDS OF GROUP I

In the two hybrids in group 1, in which one parent was susceptible to loose smut and resistant to covered smut while the other parent was susceptible to both smuts, a high degree of susceptibility to loose smut appeared in both the F_2 and F_3 generations.

When inoculated with covered smut (Table 1), 15 of 60 (25%) of the F_2 plants of the Seizure × Victor cross were infected.

There were 62 F_3 progenies grown from uninoculated F_2 plants (Table 2) and 10 were classed as resistant, 34 as segregating, and 18 as susceptible. The data for the F_2 suggest a 3:1 ratio, and the results for the F_3 correspond rather closely, although there is a shortage of pure resistant and a slight excess of susceptible progenies.

Of the 30 progenies inoculated and grown in F_3, which had not been infected in F_2, 8 were resistant, 22 segregating, and none was susceptible to covered smut.

In the 162 F_2 plants of the Scottish Chief × Victor cross, 27 (16.7%) were infected with covered smut (Table 1). In the F_3 generation, 86 progenies descended from uninoculated F_2 plants were grown (Table 2) of which 24 were resistant, 43 segregating, and 19 susceptible. The percentage of infection in the F_2 is somewhat low for a single factor difference, but the data for the F_3 fit fairly well, since there is only a slight excess of resistant progenies.

Of the 35 F_3 progenies that had not been infected when inoculated with covered smut in the F_2 generation, 7 were resistant, 27 segregating, and 1 susceptible.

HYBRIDS OF GROUP 2

As previously indicated, there were five hybrids belonging to this group. One parent, Monarch, resistant to loose smut and susceptible to covered smut, was crossed with five varieties that were susceptible to loose smut but resistant to covered smut.

In the F_2 generation (Table 1) 2.7 to 16.9% of the inoculated plants of various crosses were infected with loose smut, and 13.9 to 23.1%

TABLE I.—*Reaction of inoculated F_2 plants of eight oat crosses and their parental varieties to the Missouri races of loose and covered smut, grown at the Brooklyn Botanic Garden, Brooklyn, N. Y., 1930.**

Parental variety and hybrid	Hybrid No.	*Ustilago avenae*			*Ustilago levis*		
		No. plants grown	Plants infected		No. plants grown	Plants infected	
			No.	%		No.	%
Group 1							
Seizure (246)†	—	276	256	92.8	340	0	0
Seizure × Victor	61	—	—	—	60	15	25.0
Victor (126)	—	509	488	95.9	690	656	95.1
Scottish Chief (124)	—	306	170	55.5	276	2	0.7
Scottish Chief × Victor	62	62	49	79.0	162	27	16.7
Group 2							
Gothland (152)	—	672	645	96.0	751	0	0
Gothland × Monarch	63	79	10	12.7	79	11	13.9
Monarch (161)	—	1,079	4	0.4	1,078	1,036	96.1
Rossman (322)	—	179	161	89.9	195	0	0
Rossman × Monarch	64	59	10	16.9	60	10	16.7
Danish (309)	—	268	256	95.5	254	0	0
Danish × Monarch	65	212	31	14.6	236	35	14.8
Seizure × Monarch	67	164	21	12.8	164	33	20.1
Monarch × Scottish Chief	68	37	1	2.7	39	9	23.1
Group 3							
Danish Island (149)	—	281	267	95.0	296	25	8.4
Danish Island × Monarch	66	199	40	20.1	187	100	53.5

*Data for parental varieties cover the period from 1930–1934, inclusive.
†Special seed accession numbers used by Reed to designate his particular strains of these varieties.

were infected when inoculated with covered smut. The reaction of the F_3 progenies in group 2 shown in Table 2 that were not inoculated in the F_2 generation is summarized in Table 3.

The data in Table 3 furnish considerable evidence that the inheritance of resistance to loose smut is dependent upon a single factor difference. A single factor difference also is indicated for the inheritance of resistance to covered smut. These factors appear to be independent.

In a di-hybrid relationship there would be expected definite types of behavior in F_3 progenies that have descended from uninoculated F_2 plants, as shown in Table 4.

The interesting fact (Table 4) is that all of the expected types of behavior of the progenies have appeared in most of the hybrids. Furthermore, the classes which should be expected to contain the largest number of progenies are the ones that actually do so. The correspondence with expectation, however, is not very close. This is partly

TABLE 2.—*Distribution of F_3 progenies of various oat hybrids based on the percentage of plants infected with Ustilago avenae and U. levis.*

Smut used for inoculation in F_2 and hybrid	Hybrid No.	Infection in F_2*	Distribution and number of F_3 progenies in class centers for percentages of smutted plants												Total F_3 progenies, No.	Progenies infected, %
			Resistant	Segregating					Susceptible							
			0	5	15	25	35	45	55	65	75	85	95	100		
							Ustilago avenae									
Not inoculated																
Seizure × Victor	61	—	—	—	—	—	—	—	—	1	6	12	23	20	62	100.0
Scottish Chief × Victor	62	—	—	—	—	2	—	3	2	5	6	6	8	4	36	100.0
Gothland × Monarch	63	—	6	2	5	6	7	3	2	5	6	2	7	3	54	88.9
Rossman × Monarch	64	—	5	8	5	7	1	2	—	—	2	2	1	—	33	84.8
Danish × Monarch	65	—	8	20	13	7	11	9	6	6	4	4	3	1	92	91.3
Danish Island × Monarch	66	—	11	11	10	10	7	6	2	—	—	1	1	1	60	81.7
Seizure × Monarch	67	—	14	18	5	7	4	2	1	—	—	3	—	1	55	74.5
Monarch × Scottish Chief	68	—	4	3	3	3	3	2	1	—	3	—	—	—	22	81.8
Ustilago avenae																
Gothland × Monarch	63	12.7	16	10	9	12	4	1	2	2	—	—	—	—	56	71.4
Rossman × Monarch	64	16.9	16	7	9	6	2	1	—	—	—	—	—	—	41	61.0
Danish × Monarch	65	14.6	7	4	4	2	1	—	—	—	—	—	—	—	18	61.1
Danish Island × Monarch	66	20.1	7	10	5	5	2	2	2	1	1	—	—	—	35	80.0
Seizure × Monarch	67	12.8	15	5	7	4	1	4	1	1	1	—	—	—	39	61.5
Monarch × Scottish Chief	68	2.7	16	1	3	1	2	1	—	—	—	—	—	—	24	33.3
Ustilago levis																
Scottish Chief × Victor	62	16.7	—	—	—	2	1	5	7	8	5	6	1	—	35	100.0
Rossman × Monarch	64	16.7	6	2	2	4	—	1	1	—	—	—	—	1	17	64.7
Danish × Monarch	65	14.8	8	4	5	6	3	2	1	1	1	2	1	—	34	76.4
Danish Island × Monarch	66	53.5	8	2	3	2	3	1	3	2	1	—	—	—	25	68.0
Seizure × Monarch	67	20.1	6	7	4	6	1	5	1	4	1	1	—	1	37	83.8
Monarch × Scottish Chief	68	23.1	5	6	2	1	1	—	1	1	—	—	—	1	[illegible]	[illegible]

Ustilago levis

Not inoculated																
Seizure × Victor	61	—	10	4	9	14	5	2	1	—	1	3	7	6	62	83.9
Scottish Chief × Victor	62	—	24	8	10	18	6	1	—	1	3	6	5	4	86	72.1
Gothland × Monarch	63	—	14	10	16	5	3	—	2	1	—	—	2	1	54	74.1
Rossman × Monarch	64	—	13	3	1	5	2	1	2	1	—	3	1	1	33	60.6
Danish × Monarch	65	—	24	11	15	11	8	7	2	3	6	2	3	1	93	74.2
Danish Island × Monarch	66	—	1	7	1	4	8	7	4	8	5	8	6	1	60	98.3
Seizure × Monarch	67	—	7	3	8	15	6	1	—	—	1	5	4	5	55	87.3
Monarch × Scottish Chief	68	—	7	2	7	2	1	—	—	—	1	1	—	1	22	68.2
Ustilago avenae																
Gothland × Monarch	63	12.7	9	8	4	5	2	1	2	1	2	—	1	6	41	78.0
Rossman × Monarch	64	16.9	8	6	2	2	3	2	—	—	—	—	2	—	25	68.0
Danish × Monarch	65	14.6	5	3	3	1	—	—	—	1	—	2	1	2	18	72.2
Danish Island × Monarch	66	20.1	—	1	—	1	2	3	5	6	2	3	5	7	35	100.0
Seizure × Monarch	67	12.8	2	4	4	15	5	1	—	—	2	1	2	3	39	94.9
Ustilago levis																
Seizure × Victor	61	25.0	8	1	8	7	3	3	—	—	—	—	—	—	30	73.3
Scottish Chief × Victor	62	16.7	7	5	11	7	4	—	1	—	—	—	—	—	35	80.0
Gothland × Monarch	63	13.9	15	6	12	4	9	2	1	—	1	—	—	—	50	70.0
Rossman × Monarch	64	16.7	11	4	9	10	3	2	4	1	—	—	—	—	44	75.0
Danish × Monarch	65	14.8	9	5	10	5	1	3	1	—	—	—	—	—	34	73.5
Danish Island × Monarch	66	53.5	—	—	4	2	7	4	5	1	1	1	—	—	25	100.0
Seizure × Monarch	67	20.1	11	6	9	10	—	1	—	—	—	—	—	—	37	70.3

*Percentage of infection obtained in F_2, as shown in Table 1

TABLE 3.—*Summary of data from F_3 progenies grown from uninoculated F_2 plants in hybrids of which one parent is susceptible to Ustilago avenae and resistant to U. levis, and the other parent showing the reverse reaction.*

Hybrid	Segregation of progenies inoculated with							
	Ustilago avenae, No.				*Ustilago levis*, No.			
	Total	Resistant	Segregating	Susceptible	Total	Resistant	Segregating	Susceptible
Gothland × Monarch	54	6	23	25	54	14	34	6
Rossman × Monarch.	33	5	23	5	33	13	12	8
Danish × Monarch...	92	8	60	24	93*	24	52	17
Seizure × Monarch...	55	14	36	5	55	7	33	15
Monarch × Scottish Chief..........	22	4	14	4	22	7	12	3
Observed	256	37	156	63	257	65	143	49
Calculated (1:2:1). .	—	64	128	64	—	64	128	64

*One progeny not grown in *Avenae* series.

explained by the fact that there are too few resistant and susceptible progenies in both the loose and covered smut series, and in consequence an excess of the segregating progenies. The observed numbers, however, greatly favor the interpretation on a 2-factor basis for resistance to both smuts.

Data from the progenies shown in Table 2 that were inoculated with each smut in the F_2 generation and uninfected plants from each set inoculated with each smut and grown in the F_3 generation are summarized in Table 5.

In the progenies that escaped infection in the F_2 generation and which were inoculated with the same smut in the F_3 generation, a few proved to be susceptible. This might be expected because some of the plants of the susceptible parents also escaped infection.

When a different smut was used in the F_3 generation a considerable number of susceptible progenies were found, as might be expected if resistance to the two smuts is inherited independently.

HYBRID OF GROUP 3

Danish Island × Monarch hybrid is placed in a separate group because Danish Island is very susceptible to loose smut and slightly so to covered smut, whereas Monarch is resistant to loose smut and susceptible to covered. As noted in Table 1, 25 (8.4%) of 296 plants of Danish Island inoculated with covered smut were infected.

Many rows of this variety were grown during the different years and frequently a row would contain no smutted plants. The highest percentage ever obtained in a row was 26.3.

Altogether, 199 F_2 plants were inoculated with the loose smut and 40 (20.1%) were infected (Table 1). This result may indicate a single factor difference for the inheritance of resistance to loose smut.

TABLE 4.—*Summary of data from F_3 progenies descended from uninoculated F_2 plants of which one parent is susceptible to Ustilago avenae and resistant to U. levis, and the other parent susceptible to U. levis and resistant to U. avenae on a di-hybrid basis of inheritance.*

Smut species (Missouri races)		Segregation of progenies from hybrids					Ratio	Total progenies, No.	
Ustilago avenae	*Ustilago levis*	Gothland × Monarch	Rossman × Monarch	Danish × Monarch	Seizure × Monarch	Monarch × Scottish Chief		Expected	Observed
Resistant	Resistant	1	0	0	0	1	1	16	2
Resistant	Segregating	4	4	4	8	3	2	32	23
Resistant	Susceptible	1	1	4	6	0	1	16	12
Segregating	Resistant	7	9	14	4	5	2	32	39
Segregating	Segregating	13	7	35	23	8	4	64	86
Segregating	Susceptible	3	7	11	9	1	2	32	31
Susceptible	Resistant	6	4	10	3	1	1	16	24
Susceptible	Segregating	17	1	13	2	1	2	32	34
Susceptible	Susceptible	2	0	1	0	2	1	16	5
Totals							16	256	256

TABLE 5.—*Reaction of F_3 progenies to loose and covered smut descended from F_2 plants that had been inoculated with each smut but not infected.*

Hybrids	Reaction of F_3 progenies							
	Inoculated with loose smut, No.				Inoculated with covered smut, No.			
	Total	Resistant	Segregating	Susceptible	Total	Resistant	Segregating	Susceptible
	Loose smut (*Ustilago avenae*)							
Gothland × Monarch	56	16	36	4*	41	9	20	12
Rossman × Monarch	41	16	25	0	25	8	15	2
Danish × Monarch	18	7	11	0	18	5	7	6
Seizure × Monarch	39	15	21	3*	39	2	29	8
Monarch × Scottish Chief	24	16	8	0	—	—	—	—
	Covered smut (*Ustilago levis*)							
Gothland × Monarch	—	—	—	—	50	15	33	2*
Rossman × Monarch	17	6	9	2	44	11	28	5*
Danish × Monarch	34	8	20	6	34	9	24	1*
Seizure × Monarch	37	6	23	8	37	11	26	0
Monarch × Scottish Chief	19	5	11	3	—	—	—	—

*Possibly susceptible but escaped infection in F_2.

In the F_3 generation (Table 2), 60 progenies descended from uninoculated F_2 plants were grown, of which 11 were classed as resistant, 44 as segregating, and 5 as susceptible. On the basis of the F_2 data there should have been a larger number of both resistant and susceptible progenies.

Of the 35 F_3 progenies descended from F_2 plants inoculated with the loose smut, 7 were resistant, 24 segregating, and 4 susceptible. A larger number of resistant progenies and no susceptible ones might have been expected.

Finally, there were 25 F_3 progenies descended from F_2 plants inoculated with the covered smut; 8 were resistant, 11 segregating, and 6 susceptible.

To determine the reaction to covered smut (*Ustilago levis*), 187 plants were grown in the F_2 generation, of which 100 (53.5%) were infected. In the F_3 generation 60 progenies descended from uninoculated F_2 plants were grown, of which 1 was classed as resistant, 27 as segregating, and 32 as susceptible. In the second group of F_3 progenies there were 35 grown, none of which was resistant, 7 were segregating, and 28 susceptible. In the third group of progenies, descended from F_2 plants which had been inoculated with covered smut, of a total of 25, none was resistant, 17 were segregating, and 8 susceptible.

The most noteworthy feature of these results is the high percentage of infection in the F_2 generation and the extreme scarcity of resistant F_3 progenies; in fact, only one resistant progeny out of a total of 120 was recorded. Further, a large proportion of the susceptible progenies gave very high percentages of infection. The results distinctly indicate a different basis for the inheritance of the resistant quality. It is probable that in this hybrid susceptibility instead of resistance is dominant. There is too great a scarcity of resistant progenies and, on the other hand, too large a number of susceptible ones to indicate a simple one factor ratio.

The results with the hybrid, Danish Island×Monarch, apparently indicate a simple factor relation for resistance to the loose smut, with resistance dominant. Its behavior when inoculated with covered smut, however, suggests a reversal in behavior, with susceptibility dominant.

These results are in agreement with those previously published by Reed[5] on the inheritance of resistance to covered smut in hybrids of Gothland×Hull-less, and the inheritance of resistance to loose smut in hybrids of Monarch×Hull-less. In the F_2 generation of Gothland×Hull-less, 46% of the plants inoculated with covered smut were infected. The F_2 of Monarch×Hull-less, inoculated with loose smut, gave 31.3% infection. In both cases the percentage of infection was high for a simple factorial relationship for resistance to the smuts. When the F_3 progenies of these hybrids were inoculated with the respective smuts, an unusual preponderance of susceptible progenies was obtained. In both hybrids it has been very difficult to secure fully resistant lines of the F_3, F_4, and succeeding generations.

[5]REED, G. M. Inheritance of resistance to loose and covered smut in hybrids of Hull-less with Early Gothland and Monarch oats. Amer. Jour. Bot., 19:273-301. 1932.

SUMMARY

Results of studies of the inheritance of smut resistance in the F_2 and F_3 generations of eight oat hybrids involving varieties with contrasting reaction to the two smuts are given.

In two crosses in which both parents were susceptible to loose smut (*Ustilago avenae*), a high degree of susceptibility was obtained in both the F_2 and F_3 generations. One parent of each of these two hybrids was resistant to covered smut (*Ustilago levis*), while the other parent was susceptible and the data for both F_2 and F_3 progenies indicate a monohybrid inheritance for resistance to covered smut.

In five crosses in which one common parent (Monarch) was susceptible to covered smut and resistant to loose smut and the other five parents were susceptible to loose smut and resistant to covered smut, the data for the F_3 generation indicate clearly that resistance to the two smuts is inherited independently. As a group these hybrids have given rather low percentages of infection with loose smut in the F_2 and in most of them there also was a shortage of resistant F_3 progenies. There is much evidence to indicate that the inheritance of resistance to loose and covered smut in these hybrids is controlled by distinct single factors.

In an additional cross, Danish Island × Monarch, in which the Danish Island parent was very susceptible to loose smut and slightly susceptible to covered smut, a single factor relationship for resistance to loose smut, with resistance dominant, also was indicated. However, in the inheritance of resistance to covered smut, susceptibility apparently was dominant.

NUT GRASS ERADICATION STUDIES: I. RELATION OF THE LIFE HISTORY OF NUT GRASS, *Cyperus rotundus* L., TO POSSIBLE METHODS OF CONTROL[1]

E. V. SMITH AND GEORGE L. FICK[2]

NUT grass, *Cyperus rotundus* L., is a native of the tropics and is found in the United States from Florida to Virginia and Texas, according to Small (4).[3] The most common name of the weed in this country is nut grass, but it is frequently called coco or coco weed in the Mississippi Delta. It is generally recognized as one of the worst weeds of the southeastern states, and Ranade and Burns (3) say that it is a formidable weed of cultivation in all countries where it occurs. The general recognition of the noxious nature of nut grass has probably been responsible for the widespread popular beliefs concerning its longevity and growth capacities, many of which border on superstition.

In view of the many popular opinions and the relatively small amount of reliable scientific information about nut grass, it appeared necessary to make a life history study of the plant before commencing experiments aimed at its eradication. Results of certain phases of this study are reported herein.

THE PLANT

The nut grass plant is a complex system (Fig. 1). The below-ground portion of the plant is composed of tubers, connecting rhizomes, and roots; the aerial portion consists of rosettes of leaves and umbel-bearing scapes. The tubers are white and succulent when young but turn reddish brown and finally black with age. They consist of nodes and internodes, with buds and scale leaves at the nodes; however, the scales are sloughed off at maturity. The tubers are borne at the ends of rhizomes and are terminated by apical buds. They are relatively small, rarely exceeding 1 inch in length and ½ inch in diameter. The buds give rise to rhizomes which at first are white and succulent like the young tuber. As they grow older and the walls of the endodermis thicken, the cortical parenchyma and epidermis disappear, leaving the rhizomes black and wiry.

The rhizome may terminate in a new tuber or it may grow upward and terminate in the rosette of leaves that forms the most conspicuous element of the above-ground portion of the plant. At the juncture of the rhizome and leaves, which is below the surface of the ground, a

[1]Contribution from the Department of Botany and Plant Pathology, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication October 2, 1937.

[2]Associate Botanist and formerly Associate Botanist, respectively. This is the first of a series of papers dealing with the life history and eradication of *Cyperus rotundus* L. The manuscript was prepared by E. V. Smith. The project was outlined by George L. Fick and R. Y. Bailey, who together carried on some of the early phases of the investigation. The writer wishes to pay tribute to the memory of George L. Fick who died February 2, 1936. His careful planning made continuation of the study possible.

[3]Figures in parenthesis refer to "Literature Cited", p. 1013.

tuberous enlargement develops which has been termed a "basal bulb" by Ranade and Burns (3). The basal bulb resembles the tuber in that it contains stored food and produces new rhizomes from buds at its nodes. The progressive development of the nut grass system will be described in a later paper dealing with the histology of the plant.

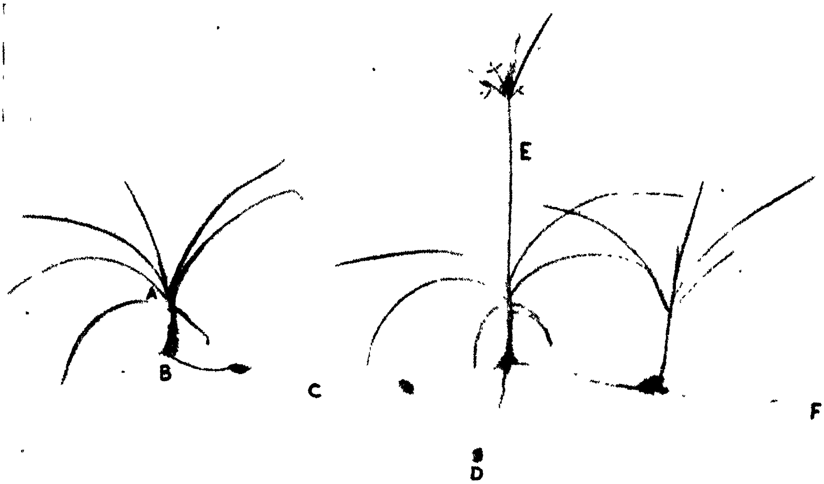

FIG. 1.—The nut grass system. (A) rosette of leaves; (B) basal bulb; (C) rhizome; (D) Tuber; (E) umbel-bearing scape; (F) young, white tuber.

APICAL DOMINANCE

When a tuber is planted the terminal bud, if present, is the first to sprout and the other buds develop acropetally. If the terminal bud has sprouted prior to the planting of the tuber, then the lateral bud nearest the apex is the first to sprout. Thus an apical dominance is exhibited in the tubers of nut grass. The following experiment presents a striking example of tuber-apical-dominance. Tubers were cut into quarters transversely and the apical and basal quarters were planted. In the apical quarters the terminal buds sprouted first, and in the basal quarters the buds near the cut surface were the first to sprout.

Evidence was obtained early in this study which indicated that the system as a whole might exhibit an apical dominance just as the individual tuber did. A count of the aerial shoots on an area did not give an accurate measure of the infestation, since many of the tubers of the system apparently lay dormant in the soil without producing aerial sprouts. It seemed probable, therefore, that some tubers of the system were suppressed by the other tubers. To test which were dominant, the following greenhouse experiment was performed:

Several nut grass systems were dug, care being taken to remove the plants intact. The systems were treated as described below and planted in 4-gallon pots of Norfolk sandy loam soil on December 14, 1931. The experiment was continued until January 16, 1932 (about one month).

In pot one, a system 43 inches long consisting of a main "chain" of eight tubers and connecting rhizomes and four lateral rhizomes bearing one tuber each was planted. At the close of the experiment only the terminal tubers of the main chain and the single tuber of each lateral rhizome had sprouted.

In pot two, a system 65 inches long consisting of 12 tubers and connecting rhizomes in a linear chain without side branches was planted. The terminal tubers and three internal tubers sprouted.

In pot three, five pairs of connected tubers were planted. Each pair of tubers had been separated from the middle of a system. Both tubers of four pairs and one of the fifth sprouted, the other tuber being dead.

In pot four, three short chains were planted, each containing three tubers. These chains had been isolated from more complex systems. All the terminal but none of the middle tubers sprouted.

In pot five, ten individual tubers that had been isolated from complex systems were planted; nine of the ten tubers sprouted, the tenth being dead.

Thus an apical dominance was shown to exist in the system as well as in the invididual tuber. This system-apical-dominance explains, in part, why cultivation frequently appears to increase the infestation of nut grass on an area. The plow breaks many connecting rhizomes and frees the internal tubers of the system from suppression by the terminal tubers. The isolated tubers germinate and produce aerial sprouts.

This knowledge should prove valuable in any system of control in which starvation of the pest is a factor. For example, if the tops of the plants are merely clipped, the starvation process will be gradual, since the system may contain many dormant tubers that serve as storehouses of reserve food. These reserve foods may be translocated from the dormant tubers as the active tubers are exhausted; after the active tubers have died the dormant tubers may then germinate. If, however, the tubers are separated from each other and all begin to germinate, then the starvation process should be materially hastened.

METHODS OF REPRODUCTION

Although nut grass produces flowers regularly in this vicinity, the junior author was unable to find viable seed. Muenscher (2), however, says that it is "a perennial, reproducing by seeds and small tubers" and the same concept appears in certain manuals (1, 4). In India, Ranade and Burns (3) found that an average of 1.5% of the seed produced was viable, so they were relatively unimportant in reproduction. The possibility of the production of viable seed in this locality is being re-investigated.

It seems probable that tubers and basal bulbs are the principal means by which the pest reproduces and spreads in the Southeast. The tubers are apparently carried to new localities with nursery stock, sweet potato and other plants, and even in Irish potato tubers. From such sources of infestation, its spread by ordinary vegetative growth is slow but sure. Tillage implements which separate the tubers and distribute them over the field spread the pest; consequently, entire farms may rapidly become infested.

RATE OF TUBER FORMATION

A new tuber may be formed in about 21 days after an isolated tuber is planted. The first rhizome to develop from an isolated tuber grows upward and produces an aerial shoot. Rhizomes formed later, either from the tuber or the basal bulb, may terminate in new tubers. In a greenhouse experiment a single tuber produced a system of 146 tubers and basal bulbs in three and one-half months.

Since a new tuber may be formed in about three weeks, any tillage operation that would break up the nut grass system at this or a shorter interval should suppress new tuber formation and lead to ultimate eradication of the weed. Immediate eradication should not be expected, since the old tubers would have to be taken into consideration and since it would be practically impossible to break every rhizome and prevent entirely the formation of new tubers by any one operation.

DISTRIBUTION OF TUBERS

The depth distribution of tubers in Norfolk sandy loam was determined. Soil from yard-square areas was removed by 2-inch layers to a depth of 20 inches. The layers were screened separately and the viable tubers counted and weighed. Results from a digging in unusually heavily infested soil are reported in Table 1. A large majority of the tubers occurred in the upper 6 inches of soil, relatively few occurred deeper than 8 inches, and none was found deeper than 16 inches.

TABLE 1.—*The number and average weight of viable tubers at various depths under a square yard area of Norfolk sandy loam soil*

Depth, inches	Number of viable tubers	Average weight of tubers, grams
0–2	537	0.16
2–4	356	0.31
4–6	409	0.42
6–8	260	0.44
8–10	62	0.25
10–12	40	0.17
12–14	12	Not recorded
14–16	0	—
16–18	0	—
18–20	0	—

The depth to which tubers grow is of tremendous practical importance, regardless of the method of eradication used. Any tillage or chemical treatment would be much more likely to succeed if all or a majority of the tubers were located in the surface soil than if many of them were located in the subsoil.

EFFECT OF DRYING ON TUBER VIABILITY

Preliminary experiments showed that isolated tubers were killed by one or two weeks' exposure to the air of the laboratory. These results were so different from popular beliefs that a more extensive experiment was performed. Freshly dug tubers were treated as follows: (a) Spread out in a single layer in a dish in the laboratory, (b) placed on

the surface of dry soil exposed to direct sunlight, (c) placed in a cloth sack in a humid storeroom, and (d) placed in a desiccator.

At intervals of four days, samples were removed from each lot for sprouting and moisture determinations. The tubers were killed by exposure of only 4 days to the sunlight, of 16 days to the laboratory or desiccator air, and of 32 days to the more humid atmosphere of the storeroom (Table 2). Under most conditions of drying the critical moisture content of the tubers appeared to be about 15%, as compared with a normal of about 50%. Death resulted when the tubers were dried below the critical moisture content. Tubers exposed to direct sunlight lost their viability at a highter moisture level (about 24%).

TABLE 2.—*Effect of drying under various conditions and for various lengths of time on tuber viability and moisture content.*

Exposure, days	Drying conditions							
	Laboratory air		Direct sunlight		Storeroom air		Desiccator	
	Moisture %	Sprouting %	Moisture %	Sprouting %	Moisture %	Sprouting %	Moisture %	Sprouting %
4	37.4	80	23.8	0	51.5	100	43.4	85
8	23.1	50	9.8	0	42.4	95	28.1	55
12	16.5	0	7.1	0	42.1	90	16.2	5
16	12.2	0	7.3	0	29.2	85	8.9	0
20	12.0	0	7.3	0	23.7	40	6.4	0
24	9.0	0	—	—	19.5	55	—	—
28	—	—	—	—	14.5	25	—	—
32	—	—	—	—	15.2	0	—	—
36	—	—	—	—	13.2	0	—	—

In another experiment in which field conditions were more closely approached, tubers were planted at depths of 2 and 4 inches in dry soil. The soil was exposed to direct sunlight but protected from rain. Eighty per cent of the tubers buried 2 inches were killed in 8 days and all were killed in 12 days. An exposure of 16 days was required to kill all of the more deeply planted tubers.

From a practical standpoint, this demonstration of the rapidity at which nut grass tubers succumb to drying is of utmost importance. Any tillage operation which would regularly turn up the tubers and expose them to the drying effects of sunlight and dry surface soil should rapidly reduce the tuber population. This could, of course, be best accomplished during dry, hot weather. The fact that most of the tubers are normally located in the surface soil might cause one to wonder why a large percentage of them does not succumb to drouth under natural conditions. The explanation is that the more superficially placed tubers are connected by functional rhizomes with tubers growing in the deeper, more moist soil. Moisture absorbed by the roots of the latter tubers may be transported by the rhizomes to the former and thus prevent their death from desiccation.

EFFECT OF TEMPERATURE ON TUBER VIABILITY

The effect of high temperatures on the viability of tubers was studied. Since it had been demonstrated that tubers were very susceptible to drying, some provision had to be made to eliminate this factor in experiments dealing with the effect of heat. It was found that tubers lost very little moisture, regardless of the temperature to which they were subjected, if they were suspended over water in a desiccator. Consequently, the tubers were placed in desiccators kept at room temperature or at temperatures of 50°, 60°, 70°, 80°, and 90° C for periods varying from 2 to 192 hours (Table 3). At the end of each interval tubers were removed and tested for viability. The tubers were not killed by an exposure of 48 hours to a temperature of 50° C but were killed by an exposure of 96 hours to this temperature. All tubers were killed by exposures of 1 hour or more to temperatures of 60° C or above.

TABLE 3.—*Effect of high temperatures on tuber viability.*

Exposure time, hours	Tubers sprouting at temperatures of					
	Room %	50°C %	60°C %	70°C %	80°C %	90°C %
0	100	100	100	100	100	100
1	100	100	0	0	0	0
2	100	95	0	0	0	0
4	100	100	0	0	0	0
8	100	100	0	0	0	0
24	100	95	0	0	0	0
48	100	100	0	0	—	—
96	100	0	0	0	—	—
144	100	0	0	0	—	—
192	85	0	0	0	—	—

Although these data indicate that summer soil temperatures may have some direct detrimental effect on tubers, it is probable that the indirect effect of increased evaporation and consequent desiccation of the tubers is of greater importance.

In an experiment dealing with the effect of low temperature on viability, tubers were stored in three locations in an electric refrigerator. The temperatures at these locations averaged 6.8°, -0.6°, and -3.8° C, respectively; the temperature at each location varied within relatively narrow limits. Samples were removed after exposures of 2, 4, 6, and 8 hours and tested for viability. Even at the lowest temperature, the viability of the tubers was not impaired. These results indicate that in the normal range of nut grass low temperatures may be of little importance in the eradication of the pest.

SUMMARY

1. The nut grass plant is described as consisting underground of a system of roots, tubers and basal bulbs, and rhizomes and aboveground of rosettes of leaves and umbel-bearing scapes.

2. An apical dominance was shown to exist in both the tuber and the system as a whole.

3. Tubers are the principal reproductive organs. The production of seed in the Southeast is controversial.

4. A new tuber may be produced in 21 days.

5. In Norfolk sandy loam soil most of the tubers were found in the upper 6 inches of soil and none was found deeper than 16 inches.

6. Tubers were readily killed by drying. Isolated tubers were killed by 4 days' exposure to direct sunlight. Usually the critical moisture content was about 15%.

7. Temperatures of 60° C and above killed tubers in 1 hour. At 50° C much longer exposures were required.

8. Exposure to a temperature of −3.8° C for 8 hours did not kill tubers.

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THE CARBOHYDRATE COMPOSITION OF CORN AND SORGHUM ROOTS[1]

JOHN P. CONRAD[2]

THE high amount of carbohydrate residues, especially sugars, in the roots of sorghums was suggested by the writer (3)[3] as one of the possible causes of the injury of this crop to succeeding ones. Certain evidence from other investigators (10) which gives support to this view has been published. Tentatively assuming that equal amounts of roots are involved, a comparison of the amounts of the different carbohydrates in sorghum roots with those of a similar crop, corn, which causes less if any injury, would be of interest. It is the purpose of this paper to present analytical data accumulated over a period of years bearing on this problem and to discuss it in the light of these and related phenomena.

PRELIMINARY STUDIES IN 1927

To get some idea of the causes of variation in sugar percentages a number of analyses were made of corn and sorghum samples taken in late October or early November, representing variations in types and varieties and in environmental conditions for the year 1927. In this, as well as in subsequent work, some difficulties in procedure were encountered. Roots which were not washed introduced a variable amount of soil into the sample. Roots which were washed lost sugars in the wash water. Consequently, the roots for each sample, freed from most of the adhering soil, were then cut up into short lengths, 2 to 20 or more grams of the fresh soil-contaminated roots being weighed out for the sugar determination and immediately boiled in about 70% ethyl alcohol. A weighed portion of the same sample was dried at 100° C, weighed, and then burned and re-weighed. The loss of weight on burning was assumed to be the dry organic matter of the crop roots. Probably only small errors are involved in this assumption as the soils in which the plants were grown were mineral ones.

The sub-sample boiled in alcohol was handled in the usual way to get an aqueous solution of the sugars which were determined (without "clearing with lead") colorimetrically by the procedure of Willaman and Davison (9) except that a factor table giving slightly different values for the ratios of the unknown to the standard was worked out for the particular colorimeter and operator. The results of these analyses are reported in Table 1. In the top of the table are given the percentages of total sugars on the basis of dry organic matter. Of the various types and varieties of corn analyzed none are very high in percentages of total sugars when compared with the sorghums. The highest percentage of sugars among the sorghums is more than 10 times that of the highest corn analyzed.

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication October 5, 1937.

[2]Associate Agronomist in the Experiment Station. A number of the analyses reported herein were made by Mr. C. P. Dutt, Mr. H. I. Sipman, and Mrs. D. P. Danno of the Agronomy Division.

[3]Reference by number is to "Literature Cited", p. 1021.

TABLE 1.—*Percentages of sugars found in the roots of corn and sorghum varieties, 1927.*

Varieties of corn and other crops	Total sugars as sucrose %	Varieties of sorghum	Total sugars as sucrose %
Golden Glow	0.14	Honey sorgo	55.4
Golden Glow	4.58	Early Amber sorgo	51.0
King Philip Hybrid	1.73	Sudan grass	30.7
Stowell's Evergreen	1.50	White Durra	54.3
White Rice pop	1.34	Feterita	40.8
A yellow dent corn	0.63	Brown Durra	38.0
Ivory King flour	0.12	Darso	27.3
German millet	2.61	Dwarf Yellow milo	16.7
Sunflower	0.85	White milo	15.9

In addition to the sorghums reported in Table 1, 19 different strains and varieties of kaowliangs were analyzed. These varied from 0.7% to 46.9%, with an average of 27.3% total sugars as sucrose (on the basis of dry organic matter). The analyses of the roots of two different varieties of milo grown under different cultural conditions are reported in Table 2. These results suggest that the greater the stress for soil moisture, the greater the percentage of sugars in the roots of these two varieties at or near maturity.

TABLE 2.—*Percentages of sugars found in two varieties of milo under various cultural treatments, 1927.*

Cultural treatment	Total sugars as sucrose, %	
	Double Dwarf	Fargo
Irrigated, flat	18.0*	30.9
Irrigated, ridged	6.5	30.7
Not irrigated	46.0†	55.5

*Another analysis gave only a trace of sugar.
†Rows were 3½ feet apart. In adjoining rows alternately 3½ and 7 feet, a sample of roots analyzed 21.5%.

CULTURE OF THE CROPS IN 1928

On the basis of the data reported in Table 1 and other considerations, it seemed desirable in 1928 to investigate the differences in sugar percentages which might result from (a) various varieties, (b) variations in the moisture supply, and (c) variations in the stage of maturity. Consequently, identical varieties and crops were planted on April 16, 1928, and grown under three different conditions of moisture supply, namely, (a) no irrigation, the soil being handled to cause the retention of a large part of the seasonal rainfall of 17.08 inches over 16 inches of which fell before planting; (b) two irrigations, one each on June 5 and July 10, each probably being between 4 and 6 inches in depth of water; and (c) six irrigations, one each on June 5, June 27, July 10, August 3, August 21, and September 12.

On September 7, 1928, a part of each variety on each moisture treatment was cut back to a 4-inch stubble to encourage growth of new shoots from the crowns.

TECHNIC OF SAMPLING AND ANALYSIS

Two different methods were used. In one, with results reported in Table 3, duplicate samples of fresh roots freed from as much adhering soil as possible, together with 1 gram each of $CaCO_3$, were boiled in alcohol. After the usual extractions, grinding, etc., the reducing sugars, reported as glucose, and the non-reducing sugars, reported as sucrose, were determined by the usual Munson-Walker method (6), omitting the washing with alcohol and ether, and the cuprous oxide determined volumetrically by the method of Bisson and Sewell (1).

As no starch was found in the roots either microchemically or gravimetrically, this usual step was omitted and hemicelluloses determined by boiling in 2% H_2SO_4 for ½ hour under reflux condenser (hemicelluloses-resulting glucose $\times 0.9$). The residue from the hemicelluloses was dried and ignited, and the weight of residue from burning assumed to be the weight of adhering soil in the sample of fresh roots. The total dry weight of the sample was determined from the weight of dried residue from the alcohol extraction and the alcohol-soluble solids. The grams of dry organic matter were the total solids of the sample less the weight of non-combustible soil and ash.

RESULTS

The results of the analyses for King Philip Hybrid corn and White Durra grain sorghum at various stages of growth and with various soil moisture treatments are reported in Table 3.

For reasons to be discussed later it was believed that the total sugars in the roots of sorghum plants cut back at maturity might be somewhat lower because of the growth of new shoots than in plants left standing after maturity. In four of the six comparisons of total sugars between the normal plants and those cut back, the percentages for the normal plants are somewhat higher than for those cut back. Because of lack of facilities only one corn variety and one sorghum variety could be handled by the method given above. Another method less exact and open to question, at least as to absolute amounts, was also employed. In this method, plants were air-dried and as much of the soil as possible separated from the roots. A sub-sample of each sample of ground roots was extracted with alcohol. Another sub-sample was used to determine moisture percentage by drying in the vacuum oven at 70° C and to determine dry organic matter by further loss on ignition. Otherwise, the analyses were carried on as for the other method. The results are given in Table 4.

It will be observed that total sugars on identical dates of sampling of White Durra grain sorghum, as reported in Table 4, are with few exceptions lower than in Table 3. The data in the table are admittedly inferior as to absolute amounts of total sugars to those in Table 3. Still in Table 4 all but two comparisons of total sugars in the plants cut back are lower than for the normal plants.

After plotting the data for total sugars in Table 3, as is shown in Fig. 1, the high percentage of sugars on the last date sampled for the corn crop receiving no irrigation seemed out of line. During the 1929 season, by tasting the stalks and roots of corn plants, it became evident that at maturity plants bearing normally filled ears contained very little or no sugar, while plants with no ears or with unfilled ears were fairly sweet. This was especially true of the stalks. Consequently,

TABLE 3.—*Some carbohydrate fractions in fresh corn and sorghum roots at different stages of growth and under different soil moisture treatments, 1928.*

Number and date of irrigations	Carbohydrates	Bloom, July 19	Soft dough, Aug. 15*	Hard dough, Sept. 6†	Mature			
					Sept. 25		Oct. 17	
					Normal	Cut back‡	Normal	Cut back‡
			Corn, King Philip Hybrid					
None	Glucose, %	6.48	5.34	1.57	2.22	—	—	—
	Sucrose, %	11.46	6.62	2.36	8.84	—	—	—
	Total sugars, %	17.94	11.96	3.93	11.06	—	—	—
	Hemicelluloses, %	7.22	12.52	7.34	8.16	—	—	—
2 irrigations: June 5, July 10	Glucose, %	6.59	2.22	1.58	0.93	0.92	0.46	0.34
	Sucrose, %	9.46	4.88	2.84	1.32	1.30	1.06	0.37
	Total sugars, %	16.05	7.10	4.42	2.25	2.22	1.52	0.71
	Hemicelluloses, %	5.98	11.21	12.86	10.44	3.30	11.02	13.67
6 irrigations: June 5, 27, July 10, Aug. 3, 21, Sept. 12	Glucose, %	3.66	1.82	1.34	0.97	1.10	0.28	0.96
	Sucrose, %	4.79	4.74	1.58	0.74	0.90	0.33	1.18
	Total sugars, %	8.45	6.56	2.92	1.71	2.00	0.61	2.14
	Hemicelluloses, %	11.09	8.06	13.18	10.74	3.62	10.61	14.49
			Sorghum, White Durra					
None	Glucose, %	6.22	—	3.04	3.36	3.76	5.76	6.70
	Sucrose, %	11.91	—	21.72	20.04	12.51	30.66	14.66
	Total sugars, %	18.13	—§	24.76	23.40	16.27	36.42	21.36
	Hemicelluloses, %	4.92	9.89	4.15	8.14	9.96	11.59	12.72
2 irrigations: June 5, July 10	Glucose, %	4.10	2.23	2.30	1.75	2.94	2.22	2.76
	Sucrose, %	30.88	30.46	26.24	14.54	19.46	29.42	10.90
	Total sugars, %	34.98	32.69	28.54	16.29	22.40	31.64	13.66
	Hemicelluloses, %	11.84	4.53	6.48	8.80	12.13	6.00	10.42
6 irrigations: June 5, 27, July 10, Aug. 3, 21, Sept. 12	Glucose, %	16.48	2.79	2.14	1.70	2.20	2.09	3.36
	Sucrose, %	14.46	17.96	12.12	15.05	16.82	18.52	16.42
	Total sugars, %	30.94	20.75	14.26	16.75	19.02	20.61	19.78
	Hemicelluloses, %	5.97	8.58	11.49	8.70	3.23	7.77	13.62

plats were grown in 1930 with irrigation treatments similar to those employed in 1928, and at maturity corn plants with normal filled ears and without normal ears were selected from each treatment. These were analyzed by the same methods as were used in 1928, and the results reported in Table 5. On this basis, it would appear as if

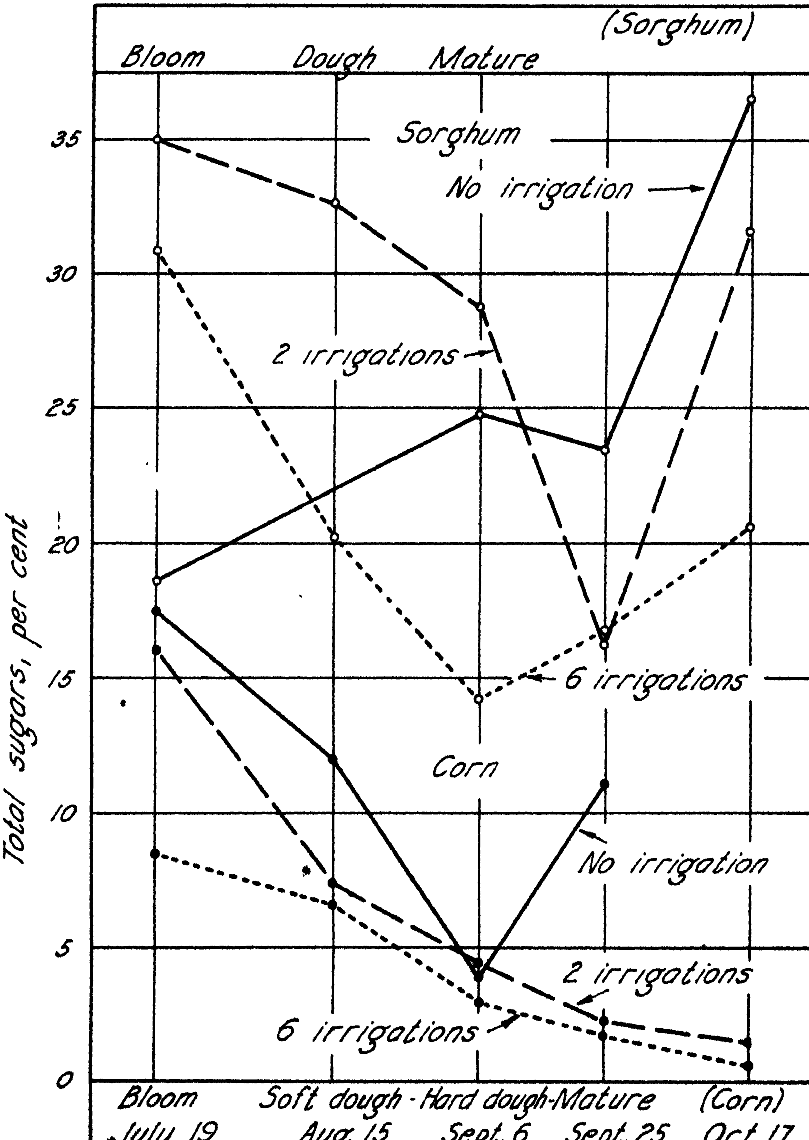

FIG. 1.—Variations in total sugars as found in the roots of White Durra grain sorghum and King Philip Hybrid corn with various soil moisture treatments and at different stages of maturity.

at least some, if not all, of the corn plants receiving no irrigation as sampled on Sept. 25, 1928, bore no ears. In the taking of samples in 1928 this factor was not appreciated.

DISCUSSION

The analytical data should be considered in the light of the field behavior of these two crops. If corn plants are cut back at maturity and if growing conditions are favorable, no second growth is made. There may be exceptions to this statement, but if so they have not come to the writer's attention. He has questioned a number of agronomists on this point and has been confirmed in his observations so far. If corn plants then are definitely annual, we would expect the sugars to be translocated to the seed even from the roots, but with normal ear development prevented either naturally or artificially, we would expect the sugars to remain in the stalks and roots. Besides the data reported herein there are other data already published (2, 7, 8) which are in agreement with this concept.

Sorghums, including broom corns, and Sudan grass under favorable growing conditions make renewed growth from the old crowns when cut back at, or near, maturity. The vigorous new growth from old stubs strongly suggests the presence of storage reserves in the roots at the time of cutting. In fact, the analyses of roots of sorghum plants cut back at maturity as reported in Tables 3 and 4 are, for the most part, in line with the idea that this new growth is made at the expense of these root reserves. Similar data on different plants have already been reported by other investigators, (4).

In the main, sorghums with us are classed as annuals; if drouth does not end the life of the plant, frost generally does. Sorghums, under favorable moisture and temperature conditions, will live over at least one winter, and have been known to live over 4 years (5) in greenhouses. We do not know how many years these plants may live, but at least under favorable conditions, sorghums are definitely perennial and therefore would be expected to have adequate supplies of food reserves in the roots. The analyses herein reported suggest that these reserves are in the form of sugars, largely non-reducing.

Though it is believed possible that the soil moisture conditions may in part be responsible for variations in the percentage of sugar, still we consider the results so far secured only suggestive and not numerous enough in themselves to draw conclusions concerning the effect of different soil moisture treatments on the percentage of sugars.

The large differences in amounts of sugars between corn and sorghums support the idea (3) that the high amounts of sugars in the sorghum roots are a contributing factor to the injury caused by sorghums to succeeding crops.

SUMMARY

1. In preliminary tests under the same cultural conditions in 1927 at maturity total sugars as sucrose in the roots varied in different types and varieties of sorghums from about 15% to over 55% on the

TABLE 4.—*Sugars as determined in air-dried samples of roots of two sorghum types grown under various treatments of irrigation and cutting back of the tops, 1928.*

Number of irrigations	Carbohydrate composition	White Durra				Standard broom corn			
		Roots sampled Sept. 25		Roots sampled Oct. 17		Roots sampled Sept. 25		Roots sampled Oct. 17	
		Normal	Cut back*	Normal	Cut back*	Normal	Cut back*	Normal	Cut back*
None	Glucose, %	4.59	3.74	6.17	6.13	5.51	2.69	3.36	6.25
	Sucrose, %	9.59	4.40	13.16	5.39	7.34	4.69	5.37	4.64
	Total sugars, %	14.18	8.14	19.33	11.52	12.85	7.38	8.73	10.89
Two	Glucose, %	7.60	7.94	10.39	7.33	4.64	3.39	10.21	9.52
	Sucrose, %	20.19	7.72	11.61	10.16	11.09	7.02	6.17	7.95
	Total sugars, %	27.79	15.66	22.00	17.49	15.73	10.41	16.38	17.47
Six	Glucose, %	7.65	4.75	7.83	4.25	4.30	1.95	5.05	3.87
	Sucrose, %	12.16	4.15	9.00	7.30	5.20	1.01	5.65	3.13
	Total sugars, %	19.81	8.90	16.83	11.55	9.50	2.96	10.70	7.00

*Tops removed from these plants on Sept. 7, 1928, leaving a 4-inch stubble.

TABLE 5.—*Some carbohydrate fractions in the fresh roots and stalks of King Philip Hybrid corn plants with and without normally filled ears, 1930.*

Number of irrigations	Normally filled ears	Glucose, %		Sucrose, %		Total sugars, %		Hemicelluloses, %	
		Roots	Stalks	Roots	Stalks	Roots	Stalks	Roots	Stalks
None	Present	0.30	0.46	Trace	0.00	0.30	0.46	7.66	Lost
	Absent	0.77	7.90	3.02	39.30	3.79	47.20	8.58	7.80
Two	Present	0.27	.23	0.00	0.00	0.27	0.23	11.22	8.50
	Absent	0.70	2.47	3.06	8.18	3.76	10.65	8.11	7.40
Six	Absent	1.18	1.78	5.17	6.22	6.35	8.00	9.15	8.18

basis of dry organic matter, while in corn varieties they varied from much less than 1 to about 4.5%.

2. In more extensive experiments in 1928 under different soil moisture conditions, the sugars in corn (King Philip Hybrid) decreased from amounts varying from about 8.5 to nearly 18% at the blossom stage down to amounts, with one exception, below 2.5% at maturity. This suggests a movement of sugars to the ear during the maturing of the crop. Sugars in sorghum (White Durra) with but few exceptions remained above 16% from bloom to maturity, with many of the samples being over 30%.

3. There are indications that sorghums cut back at maturity make new shoot growth at the expense of sugars stored in the roots.

4. In corn plants without seed-bearing ears at maturity in 1930 the sugar percentages were consistently higher in both roots and stalks than in those plants with seed-bearing ears. This was especially true in regard to stalks.

5. These data are consistent with the view that corn is physiologically an annual while sorghums are perennials.

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A PHYSIOLOGICAL STUDY OF COLD TOLERANCE IN CORN[1]

L. V. SHERWOOD[2]

CORN is often killed by the first cold period in the fall and is therefore unable to take advantage of a probable two to six weeks' period following during which it could otherwise continue to grow and mature. Hughes and Robinson (7)[3] have shown that there has been a gradual increase in corn yields in recent years. They indicate, however, that the percentage of marketable corn has decreased and attribute this to the selection of large ears for seed. Large ears require a long growing season for their production. This has brought about late-maturing strains which may be injured by early fall cold weather.

Damage done to corn by early frosts was illustrated in the fall of 1935 and its effect was reflected the following spring in prices of $5 to $10 or more a bushel for seed. All strains of corn are not equally susceptible to frost injury. The development of cold-tolerant strains would prove a boon to the farmer's income. An increase of 5 bushels or more per acre could easily be realized in some cases were corn cold tolerant. The damage done to corn by cold is likely to be much greater if one considers both yield and quality of grain. This may be difficult to realize because many times damage from cold injury is present in corn but not in an apparent manner.

Workers have already been able to obtain strains of corn highly susceptible and also highly tolerant to cold. However, need for additional information has stimulated many investigators in an effort to determine further the factors underlying differences in cold reactions. An understanding of the factors underlying cold tolerance in plants would materially aid not only corn growers, but growers of wheat, fruits, vegetables, and other crops as well. It would also enable one to understand better the vital phenomena of protoplasm. The fact that plants are capable of changing from time to time in response to environment their ability to withstand cold indicates beyond a doubt the close relationship between this function and life itself.

Investigators have attacked the problem of cold susceptibility by various methods. Many of them have been interested in the physicochemical point of view, often with special reference to bound water. Gortner (3) and others have endeavored to establish a relationship between bound water and colloids in plants. This approach ordinarily involves the colloidal complex and physical or chemical measurements of tissue not in its natural functional condition. It would appear that any effort to study cold endurance which involves measurements on isolated plant tissues, as commonly used in bound water studies, may be as fundamentally incorrect as trying to study heart beat, blood circulation, or nervous reaction in isolated animal tissues, and a true solution to the problem is thwarted from the beginning. Con-

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Received for publication October 18, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 1029.

sequently, any explanation of living phenomena involves not only a physico-chemical but also a biological explanation.

Furthermore, dealing with protoplasm as if it were homogeneous or uniform in reaction to stimuli is like dealing with a human being as if he were a simple homogeneous structure. When cold is applied to a plant and it dies, it is probably a mistake to assume that the cold was equally injurious to all chemical portions of the protoplasm. It may be that cold affects some vital constituent somewhat analogous to the effect of some unfavorable condition on the human heart. It is necessary to determine what portion of the protoplasm is affected in order to understand properly cold injury in plants.

A possible means of making such a study may lie in the fact that certain chemicals affect one portion more than others. It may be possible to treat protoplasm, such as that found in seed, with a chemical which will modify either favorably or unfavorably the ability of the seed to withstand cold. Subjection to cold following this treatment should give an indication of effect of the chemical used when germination and growth are checked against that of non-treated seed. Such a method offers a means of studying the tissues of the seed or plant in a functional state without killing or severing them.

MATERIALS AND PROCEDURE

This investigation has been carried on for two years, 1934 to 1936. The method used was designated to avoid as much as possible a disrupted or abnormal condition of the plant. Two top-cross strains of corn were chosen, Krug×Tr, which is cold tolerant, and Krug×R4, which is cold susceptible. By using corn of known performance in respect to cold tolerance it was possible to study cold effects by noting the differences in reactions of these two strains. It seemed that a study of different chemical solutions and their differences in effect upon these two strains of corn might give some insight into the problem of cold endurance.

Most workers who have dealt with salts have spoken only of the cation effect. In choosing salts for this study, calcium chloride and calcium nitrate, as well as both potassium chloride and potassium nitrate, were used in order to include any possible anion effect. Preliminary tests showed that concentrations of the chemicals should be as dilute as 0.1 to 0.5% by weight in order to be effective.

Samples of corn, 10 kernels each, were sorted for uniformity and freedom from injury and placed in glass test tubes (5/16 inch in diameter and 6 1/14 inch long) for soaking in the chemical solutions prepared. The test tubes were then filled about one-third full of solution, stoppered with a rubber stopper, and allowed to soak at room temperature (generally about 22° to 25°C) for 12, 18, and 24 hours. The solutions were then drained off and the test tubes, with corn enclosed, were exposed to refrigeration temperature of generally —5°C for 12 hours, and finally the corn was planted in a sand flat to test its ability to grow.

In some cases results secured in these tests were checked under field conditions to determine whether the effects of the salts carried over throughout the life of the plant. Field trials also served as a check on the validity of Kidd and West's (9) assumption of physiological pre-determination, in which they considered it possible to affect materially later stages of development in the plant by some earlier treatment, such as one applied in the seed stage. Data were taken at harvest time to determine whether any relationship existed with data in the seedling stage.

In order to secure regulated low temperatures in treating the nearly mature plants in the fall, a large field refrigerator was used, such as that described by Holbert, Burlison, and Johnson (5). Plantings in the field were made in a four-hill-square design or plan so that chemically treated corn, exposed and unexposed to low temperatures in the seed stage, of both cold-tolerant and susceptible strains would all appear close enough together to be covered all at one time by the field refrigerator. Other plantings were made so that yield and other data could be taken. In some cases corn was harvested from these plantings and treated the same as the parental seed, then germinated to determine whether the results checked with the parental seed treatments or with effects obtained in field refrigeration of the parental plants.

Field results were obtained for two seasons, 1935 and 1936. Treatments of seed for field plantings were made in the same manner as for sand flat germination, except for quantity. For 1935 the seed was germinated and only the surviving seedlings were transplanted into the field, while for 1936 the seed was exposed to —2° instead of —5° C. At —2° C the seed were not killed and consequently the corn was seeded directly into the field without germination. In 1935, 20 hill-replicated plats were used, while in 1936, 10 hill -replicated plats were used because of shortage of seed.

Plant tissues exposed at or below 0, the freezing point of free water, are commonly spoken of as "frozen"; however, not all of the protoplasmic constituents are necessarily congealed. The ambiguity thus involved is avoided by the use of the term "refrigerated" instead of the term "frozen".

EXPERIMENTAL RESULTS

EFFECT OF SALTS ON CORN IN THE SEED STAGE

After preliminary work, a test (Fig. 1) was secured which showed the effect of the chemicals chosen against cold treatments. It is evi-

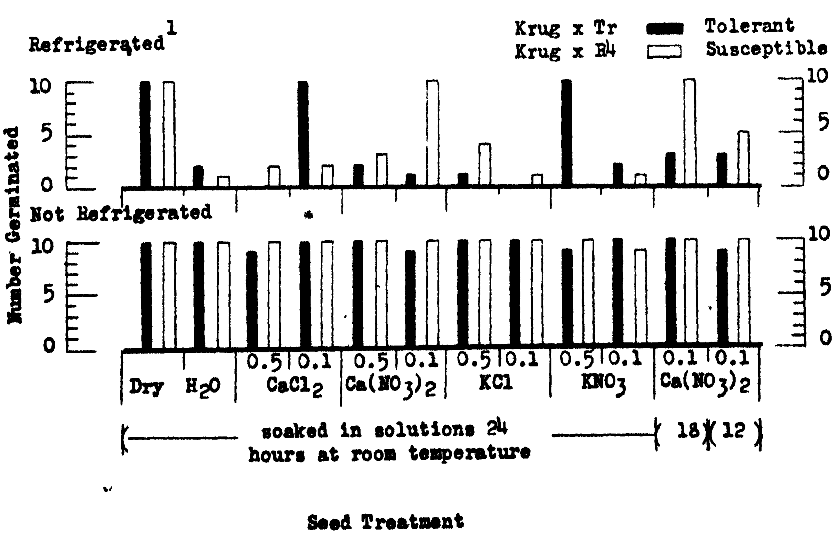

FIG. 1.—Germination of corn, showing the effect of low temperature on kernels previously soaked in various salt solutions (March 3, 1935).

[1]Refrigerated 12 hours at —5° C after chemical treatment, before germination in sand flat.

dent that in certain instances the corn was protected against cold injury by the chemicals. The calcium salts of 0.1% concentration and the potassium salts of 0.5% concentration seemed to be most effective, while other concentrations of these salts gave less protection. It is interesting that the calcium salt protected the tolerant strain in the presence of the chlorine anion and protected the susceptible strain in the presence of the nitrate anion. With potassium salts this relationship was reversed, indicating that this protectiveness depends not only upon the cation effect but also upon the anion effect. The consistency with which 0 1% calcium nitrate protected the susceptible strain, as well as other consistent behaviors, tends to eliminate chance in deciding which sample of corn should be and which should not be killed by exposure to low temperatures. All results consistently checked in this test except the 0.5% calcium chloride treatment.

EFFECT OF TREATING SEEDS WITH SALTS UPON LATER GROWTH AND DEVELOPMENT

Plantings were made May 29 in 1935. The method of cultivation was the same as for any other corn on the Agronomy South Farm. Because of an early killing frost no artificial refrigeration could be made. However, certain field data were taken October 10 after a killing frost October 6. Considerations were given to maturity, cold injury, general vigor, height of stalk, lodging, and size of stalk. An average was calculated for the number of hills present for any one treatment. The corn was harvested November 3, 1935, and yield comparisons were made.

In 1936 the corn was planted May 23 and observational data were taken September 26. Yield data on corn and fodder were taken October 25. Even though grasshoppers and drouth caused premature ripening, refrigeration was made on six different treatments. Corn soaked 24 hours in water, 0.5% $CaCl_2$, 0.5% $Ca(NO_3)_2$, 0.5% KCl, 0.1% KCl, and 0.1% KNO_3 was exposed to refrigeration temperatures during the period of September 16 to 23. Cold injury was noted by leaf discolorations and wilting. Injury data were taken October 2.

In comparing the effects of chemical treatments on cold tolerance in 1935 and 1936 with those in the seed stage, it appeared that some relationship existed between protection by the chemicals in the seed stage and in the later stages of growth. This was especially true of the calcium solutions.

There apparently was very little relationship between the effects of chemical treatments on the parental seed against freezing injury and the effects upon the progeny. Genetic segregation and introduction of foreign pollen were probably significant factors causing variation.

Corn seed produced on plants from chemically treated and refrigerated seed and also from chemically treated but not refrigerated was gathered and soaked 24 hours in water and refrigerated for 12 hours at —5° C. Greater injury was obtained in seed gathered from plants grown from seed which had been refrigerated than from that grown from seed which had not been refrigerated.

No significant differences showed up in maturity in 1935, since all

the corn was prematurely killed by frost. In 1936 corn seed treated with 0.5% $CaCl_2$, 0.5% and 0.1% KCl, and 0.1% $Ca(NO_3)_2$ showed greater differences in maturity than corn exposed to other treatments. The 0.5% $CaCl_2$ treated corn from refrigerated seed was more mature than from non-refrigerated in both the tolerant and susceptible strains. Of seed treated with 0.1% KCl, the refrigerated was less mature in both strains. The same was true of 0.1% $Ca(NO_3)_2$ treated corn. When treated with 0.5% KCl, the susceptible strain, both refrigerated and not refrigerated, was more mature than the tolerant strain.

An attempt to explain differences in maturity by differences in number of nodes was not successful. Yield data indicated that a direct relationship existed between maturity and total weight of fodder and grain for any one chemical treatment in the susceptible strain. Such a relationship did not hold in the tolerant strain.

It appeared that chemical treatment in the seed stage has no appreciable effect upon general vigor of the corn. It appeared, however, that "iarovization," or "vernalization" described by McKinney and Sando (11), may have played a part, since the vigor of corn produced from refrigerated seed differed from that produced from non-refrigerated seed. In 1935 the susceptible strain seemed to benefit more than the tolerant from refrigeration, while in 1936 the opposite was true. The year 1935 was wet, while 1936 was dry.

There apparently was no consistent relationship between seed treatment and height of stalks produced. There was no apparent relationship between size of stalks and chemical treatments. However, there was a difference in reaction of the two strains to refrigeration, the size of stalks being largest in most cases in both strains where refrigerated. There was no apparent relationship between seed treatment and lodging.

FIELD REFRIGERATION

The use of a potentiometer with thermocouple connections made it possible to obtain various temperatures (Fig. 2) during field refrigeration. All refrigeration was done at night, since at night the temperature naturally drops. Potentiometer readings were made on three different refrigeration "sets".

In plants produced from seed pretreated with 0.5% $Ca(NO_3)_2$, the temperature of the leaves lagged about 2° C behind the refrigeration temperature, as it was lowered, while the ear temperatures lagged about 4° to 6° C behind those of the leaves. Similar results were found by Burlison and Holbert (1). These differences gradually narrowed toward morning as the temperatures became lower and dropped more slowly. Apparently there were no significant differences in temperature lag of either the ear or leaf tissues in the two strains of corn used.

There were consistent differences in the temperature lag of the stalk tissues. The stalk tissue of the tolerant strain appeared to be better insulated than that of the susceptible. The temperature of the susceptible strain was approximately a degree lower than that of

the tolerant as the temperature decreased. In the susceptible strain, where treated with $CaCl_2$ the temperature of stalk produced from nonrefrigerated seed consistently exceeded that produced from refrigerated seed. This difference probably was due to individual differences between plants within the strain rather than to any differences due to previous exposure of the seed to low temperatures. This conclusion tended to be verified by the fact that there was no consistent difference in the tolerant strain. The conclusion is further substantiated by the fact that the relationship was reversed where the seeds were soaked in water. However, in order to come to final conclusions it would be necessary to have more samples.

DISCUSSION

NATURE OF SALTS AND THEIR EFFECT UPON PLANT TISSUES

Salts of calcium and potassium were chosen mainly because of the contrast in their effects upon protoplasm. Various workers have shown that salts constituted of cations having higher valence were more deleterious in effect than those of lower valence. Sellschop and Salmon (15) found that KNO_3 gave a greater protection against cold injury than any other salts used, leaving KCl, $CaCl_2$, $Ca(NO_3)_2$, NaCl, and $NaNO_3$ in the order named. The water check fell between KCl and $CaCl_2$. Fox (2) found that potassium salts in dilute concentrations permitted more leaching of nutrient materials from seeds than distilled water, while calcium salts permitted less. She correlated more leaching with monovalent salts and less with divalent salts.

Johnson (8) observed that soaking *Avena fatua* in KNO_3 solutions aided in breaking dormancy and thereby stimulated activity. Osterhout (12)

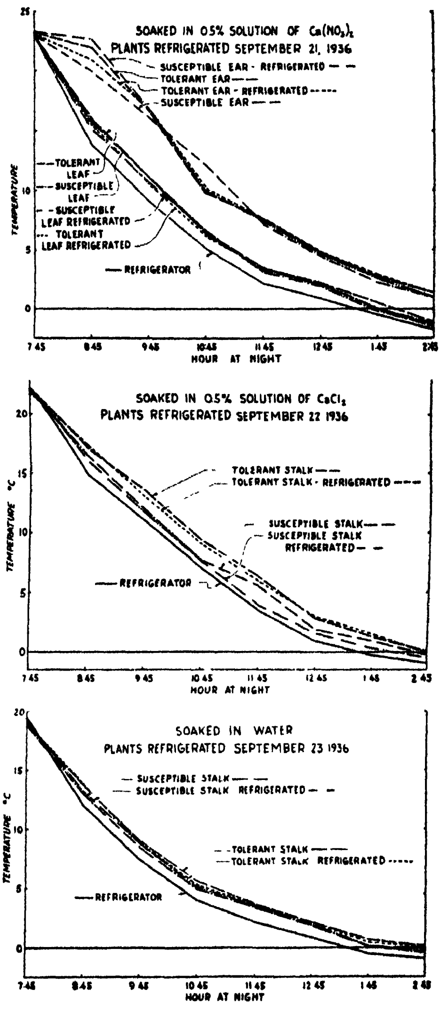

FIG. 2.—Temperature changes produced by field refrigeration in tissues of cold-tolerant (Krug × Tr) and susceptible (Krug × R_4) strains of corn produced from seed soaked 24 hours at room temperature in various solutions, part of the seed then being refrigerated 12 hours at —2° C before planting May 23, 1936.

and Spaeth (16) found an increased viscosity of protoplasm when tissue was placed in $CaCl_2$ solutions; and under prolonged application this increase was followed by a decrease. Osterhout (12) showed that viscosity of protoplasm is reversible if not carried too far. Heilbrunn (4) and Fox (2) have shown that viscosity is also a function of temperature. Fox maintains there are heat coagulable proteins which coagulate at different temperatures, indicating that it is possible to injure or affect one protoplasmic constituent without necessarily affecting the remainder. Hottes (6) showed that internal portions of the cell differ and that not all physical and chemical constituents of the individual cell react the same to stimuli. Seifriz (14) states that "protoplasm undergoes very rapid changes in viscosity and, with possible rare exceptions, all parts of the cell are not of the same consistency".

It may be that an increase in viscosity by a salt is of a similar effect to that of heat, and the effect of the salt is to coagulate one or more of the proteins. Marrack and Thacker (10), in working with animal tissue, showed that "calcium forms an un-ionized compound with proteins", indicating that calcium does affect the proteins.

Certain proteins may be coagulated without death to the plant, and as long as only these are coagulated a reversibility in viscosity is possible since there would still be other proteins to carry on the functions for a time. Proteins probably vary in their resistance to the effect of chemical salts, but if left in contact with any salt long enough they may all be coagulated and thus bring about death; then reversibility of reaction would no longer be possible. In the case of exposure to certain chemicals all the various proteins may be affected beyond reversibility and so nearly simultaneously that these different reactions are not observed. Some of the differences in the reaction of seeds to calcium and potassium salts may be of this nature.

Incidentally, if a protein, which is not needed for normal immediate functions, is injured in the plant, this injury will perhaps not show up until later in life when normal functions of the plant necessitates use of the particular protein injured. This may account for cold injury effects which are not apparent at the time of exposure but which show up later in the life of the plant.

It is likely that the chemical salts used affect the nutritional relationship of the cell and in this manner affect the cold tolerance of the plant. Many workers have shown that plants grown on fertile soils having well-balanced fertility generally exhibit a greater tolerance when exposed to low temperatures than do plants grown on poor soils. An improper nutritional balance in plants may cause weaknesses in plants much the same as it might in animals. It is possible that the salts used in these experiments affected the nutritional relationship of the corn, perhaps through their effect upon the proteins.

As indicated earlier, workers have stressed the effect of the cation of a salt used to induce or inhibit cold tolerance in plant tissue, but have given little attention to the anion. It has been shown that it is necessary to consider both cation and anion. They act differently upon different kinds of seed possessing proteins of probable wide differences in quality. These differences in proteins must be con-

idered and it is not sufficient to consider quantity alone. Rudolfs (13), states that, "differential absorption of ions is greatly influenced by the amphoteric character, amount, and kind of proteins present in the seeds."

On the basis of a theory of protein coagulation or stimulation to account for the effect of salts upon cold tolerance, it would appear that in some ionic combinations in the presence of certain protein constituents, the ions act physiologically antagonistic and are unable to activate any stimulatory effect against cold injury. However, this same ionic combination, in the presence of other protein constituents, perhaps such as found in another strain of corn, appears to be physiologically compatible and lends a stimulatory effect which protects the system against cold injury. The fact that being either physiologically antagonistic or compatible for a particular salt depends upon the strain of corn used indicates that the proteins of the two strains, assuming the action to be upon the proteins, have some physiological characteristic which is precisely in contrast one with the other. The problem then resolves itself into finding what particular physiological differences exist in the proteins associated with cold tolerance.

SUMMARY AND CONCLUSIONS

1. It is possible that a "vernalization" effect, such as described by McKinney and Sando, is induced in the refrigeration of corn seed.
2. In these experiments cold-tolerant strains of corn apparently have a better stalk insulation against cold than do susceptible strains.
3. Tolerance in corn appears to be a function of proteins. Protein variation in plants may account for differences in cold tolerance due to concurrent nutritional differences. Proteins may vary in quantity or quality or both.
4. Differences in cold tolerance of tissues caused by exposure to chemical salts may be attributed to effects upon nutrition, the proteins being the constituents affected.
5. Natural cold tolerance in a strain of corn in the seed stage can be temporarily retarded by soaking the seed in certain chemical solutions. It is also true that the same chemical treatment may impart an induced cold tolerance to an otherwise susceptible strain.
6. Generally speaking, protection of corn against cold injury by soaking the parental seed in chemical solutions probably affects the plant most in the younger stages and wears off as the plant grows older.

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REGISTRATION OF IMPROVED WHEAT VARIETIES, XI[1]

J. ALLEN CLARK[2]

TEN previous reports present the registration of 53 improved varieties of wheat. In 1936, two varieties were registered and, as in former years, the previous registration was referred to.[3]

Two varieties were approved for registration in 1937, as follows:

Varietal Name	Reg. No.
Canawa	319
Apex	320

CANAWA, REG. NO. 319

Canawa (W. Va. I–22–1125, C. I. 11854) was developed by selection at the West Virginia Agricultural Experiment Station, Morgantown, W. Va. It is the best of 125 plant selections made from Canadian Hybrid, a mixed commercial wheat grown in that state. The selections were made in 1921 by R. J. Garber who applied for the registration of Canawa after testing it in comparison with other selections and varieties from 1923 to 1935.

Canawa has purple stems, is awnleted, has white glabrous glumes, and short, soft to semi-hard red kernels. Its superior characters are high yield, stiff straw, and good (non-yellow berry) kernels. The new wheat was first distributed for commercial growing in 1935. The comparative data upon which registration is based are shown in Table 1.

TABLE 1.—*Comparative yields of Canawa and other standard soft red winter wheats grown in nursery experiments (four-replications) at Morgantown, W. Va., 1931–1935.**

Variety	Yield in bushels per acre						Percentage of Trumbull
	1931	1932	1933	1934	1935	Av.	
Canawa (new)	18.6	21.1	25.8	21.6	34.4	24.3	109.5
Fulhio (standard)	25.1	17.1	22.4	22.7	29.6	23.4	105.4
Trumbull (standard)	22.1	16.7	21.7	22.9	27.8	22.2	100.0

*For further information on Canawa wheat see W. Va. Agr. Exp. Sta. Bul. 272, by R. J. Garber and L. S. Bennett.

APEX, REG. NO. 320

Apex (Sask. No. 1703, C. A. N. No. 1857; C. I. 11636) was developed from a hybrid between H-44-Double Cross (F_1) × Marquis,

[1]Registered under the cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 2, 1937.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1937 Committee on Varietal Standardization and Registration of the Society, charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, X. Jour. Amer. Soc. Agron., 28:1017–1018. 1936.

made at the University of Saskatchewan, Saskatoon, Sask., in 1927. The cross and selection resulting in Apex were made by J. B. Harrington, who applied for its registration. The strain was tested for 6 years in Saskatoon, and for 4 years at 12 stations in Alberta, Saskatchewan, and Manitoba, Canada.

Apex is a hard red spring wheat with awnleted spikes and white, glabrous glumes, resembling Marquis in general appearance. The superior characters of Apex are resistance to stem rust, high yield, and quality. The variety was distributed for commercial growing in 1937. The comparative data upon which registration is based are shown in Table 2.

TABLE 2.—*Comparative yields of Apex and other standard hard red spring wheats grown in nursery experiments (four to six replications) at 12 experiment stations in Alberta, Saskatchewan, and Manitoba, Canada, 1933–1936.**

Variety	Yield in bushels per acre					Percentage of Marquis
	1933	1934	1935	1936	Average	
Apex (new)	35.7	29.6	26.3	18.3	27 5	110.0
Marquis (standard)	34.8	28.4	19.4	17.4	25.0	100.0
Reward (standard)	28.7	27.2	22.4	16.9	23.8	95.2

*For further information on Apex wheat see Univ. Saskatchewan, Field Husb. Dept., Circ. No. 534, Oct. 1935 (Mimeographed). The Western Producer, Oct. 3, 1935 (Published at Saskatoon weekly by Sask. Wheat Pool.)

BARLEY VARIETIES REGISTERED, IV[1]

H. K. HAYES[2]

PREVIOUS reports have included descriptions of the six improved varieties of barley that have been registered (1, 2, 4)[3]. The variety approved for registration in 1937 is of similar parentage to Velvet and Glabron described by the registration committee in 1928 (2). It was obtained from the Minnesota Agricultural Experiment Station among 20 unnamed hybrids from backcrosses of a purified strain of Manchuria × Lion backcrossed to Manchuria, which were developed as a part of the breeding project carried on cooperatively between the University of Minnesota and the U. S. Dept. of Agriculture.

After 3 years of comparative testing in Saskatchewan, the Minnesota hybrids were all discarded except one which was outstanding for yield and vigor. Before increasing and introducing the new variety it was purified by mass selection. It has been described under the name of Regal by Harrington (3) who introduced the new variety and requested its registration. Harrington has estimated an annual production of 100,000 acres in western Canada.

[1]Registered under the cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 8, 1937.

[2]Chief, Division of Agronomy and Plant Genetics, Dept. of Agr., Univ. of Minn., St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of barley varieties.

[3]Numbers in parenthesis refer to "Literature Cited", p. 1033.

REGAL, REG. NO. 7

This is a smooth-awned, six-rowed variety resembling Manchuria. Regal has been outstanding in yield, straw strength, neck strength, and weight per bushel in tests in the Province of Saskatchewan. The plant is of medium height, with leaves of a lighter green color than most other varieties of barley. The heads are of medium density. The awns are quite smooth for two-thirds of their length. The rachilla is short, with long silky hairs, and there are a few short barbs on the veins of the kernels. Regal was grown at various experiment stations in western Canada from 1928–30 and increased for distribution in 1931. Comparable yields are given in Table 1.

TABLE 1.—*Comparative yields at Saskatchewan stations.*

Location	Years tested	Average yield, bu. per acre			
		Regal	O A.C. 21	Hannchen	Trebi
Saskatoon	1928 30	74.2	56.7	60.1	75.4
Indian Head	1929-30	46.3	40 8	44 3	58.5
Rosthern	1930-31	68.2	55 2	62 7	64.4
Scott	1928 31	49.8	37.6	50 7	42.6
Swift Current	1930	30.2	23.9	22.9	37 7
Average		53.7	42 8	48.1	55 7

Regal is somewhat inferior to O.A.C. 21 in malting quality, but much superior to Trebi. Harrington states, "Where both the grain and straw are used for feeding stock, Regal's inferiority to Trebi in grain yield is more than compensated for by its smooth awns and long, strong straw."

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3. HARRINGTON, J. B. Regal, a new variety with smooth awns. Univ. of Sask. Col. Agr., Agr. Ext. Bul. 77. 1937.
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BOOK REVIEWS

STATISTICAL METHODS

By George W. Snedecor. Ames, Iowa: Collegiate Press, Inc. xiii+341 pages, illus. 1937. $3.75.

BEGINNING with the studies of "Student" and followed later with the extensive development by Fisher, the small sample theory has steadily advanced until at present it occupies a very important place in statistical analysis. This method is especially adapted for use by investigators in agriculture and biology because of the limited amount of data that is practical in many experiments of such workers. Dr. Snedecor's book is limited very largely to small sample

methods, certain phases of large sample statistics being omitted and others given less attention.

Treatment of the subject matter seems well balanced and the arrangement is intended to develop and explain the meaning of the various concepts from the more simple to the more complex in a manner that can be grasped by the investigator who is not highly trained in mathematics. In fact, a knowledge of arithmetic and the rudiments of algebra alone are required to follow the numerous examples that have been worked out to illustrate principles and methods of computation. It appears that the author has succeeded excellently in accomplishing his aims. In a work of this kind, naturally, many topics are discussed in much the same manner as found in other works, excepting, of course, the individuality of the writer.

The entire book is very well written. There are, however, certain subjects which should be mentioned as being either outstanding or that are new contributions of the author. The many uses of chi square, the various chapters on regression, covariance, and the section on fitting orthogonal polynomials are exceptionally well written and distinctive. In various portions of the volume, but especially in Chapter 15, new ideas and original methods of computation are presented.

Numerous examples are worked out in the text and many problems to be worked by the student occur throughout the book and each chapter ends with references to literature cited. The examples are drawn largely from agricultural experiments.

Chapter headings are as follows: Experiments on Attributes; An Experiment Designed to Compare Measurements of Individuals; Sampling from a Normally Distributed Population; An Experiment Designed to Compare Two Groups; Short Cuts and Approximations: Linear Regression; Correlation; Large Sample Theory; Enumeration of Data with More Than One Degree of Freedom; Experiments Involving More Than Two Groups of Measurement Data; Analysis of Variance; Analysis of Data with Two Criteria of Classification; Two Variates in Two or More Groups; Covariance; Multiple Regression and Covariance; Curvilinear Regression; Individual Degrees of Freedom; and Binominal and Poisson Distributions. A general index and index of symbols completes the book.

Since the appearance of Fisher's "Statistical Methods for Research Workers", several works, of which Dr. Snedecor's book is one, have appeared devoted either partly or entirely to small sample statistics in which the aim has been to explain and illustrate by numerical examples the principles contained in Fisher's work. Each writer has presented the theory in different ways; either in explaining the theory, in the numerical examples, in the emphasis placed on different phases of the science, or in the material included or omitted. Any biologist who wishes to learn how to analyze his experimental data would do well not to rely upon the text of any one author but should have a number of works dealing with the same subject. By a study of each he should avoid misinterpreting the application of the theory and computation to his experiments but, best of all, he will learn different ways in which he will be able to improve his experimental technic.

Dr. Snedecor's book should be in the library of everyone who desires to acquaint himself with the theory and practice of small sample statistics. It is one of the best works on the subject. (F. Z. H.)

PERENNIAL VARIETIES OF CULTIVATED CROPS

By A. I. Derjavin. Moscow: State Agr. Press. 48 pages, illus. 1937.

THIS pamphlet is one of a series of booklets in Russian under the general title of "What is New in Agriculture". The author discusses perennial forms of cereals, legumes, so-called "technical crops", such as sunflower, artichoke, and flax, and vegetable crops. Other chapters deal with the advantages and disadvantages of perennial crops over annuals and a description of the methods employed at the Experimental Branch Station for Perennial Crops at Voroshilovsk in the northern Caucasian Region. (J. W. P.)

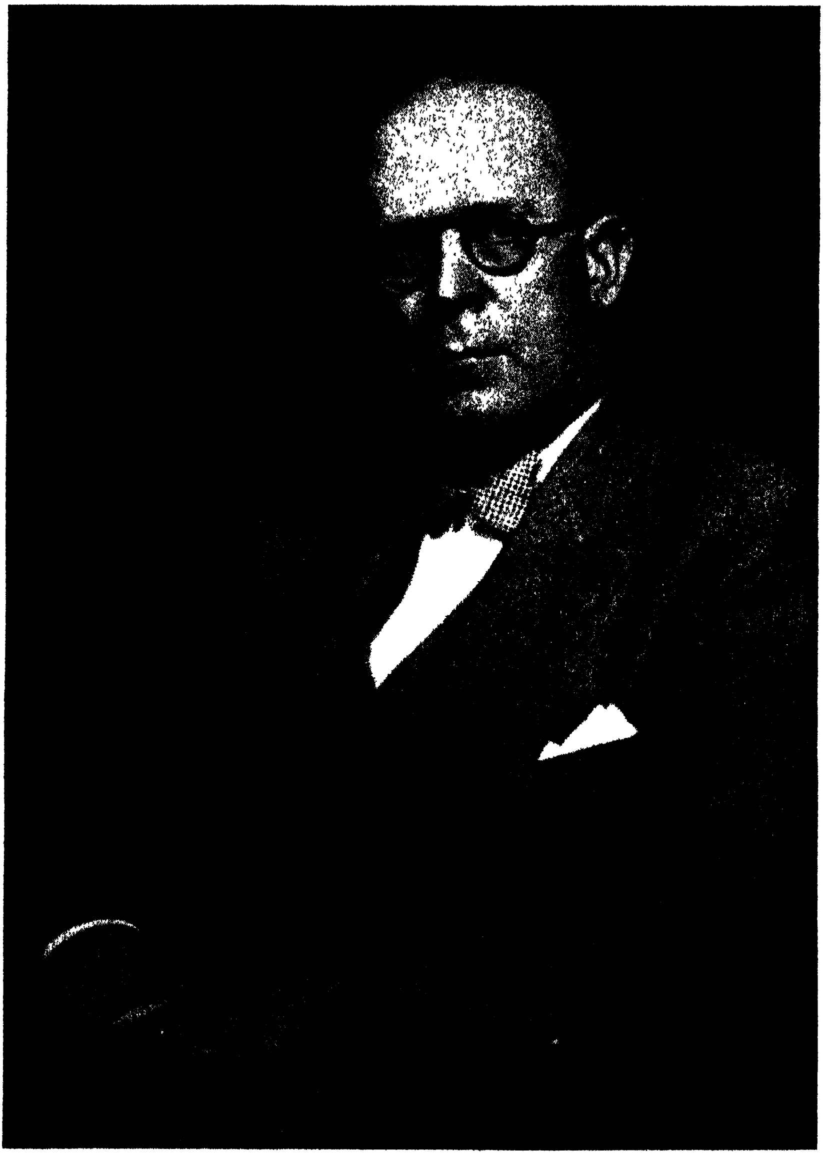
THE THEORETICAL BASIS OF PLANT BREEDING

Edited by N. I. Vavilov. Moscow: State Agr. Press. 3 vols. 1936–37.

THREE volumes of this work are published entirely in Russian with the exception of some titles and a complete index in Latin to names of plants, diseases, and insect enemies. The contributors selected by Professor Vavilov include the leading workers in their several fields, and these three volumes, each containing more than 800 pages, are a real contribution to the subject of plant breeding.

The first volume is devoted to general problems and methods of plant breeding with an introductory chapter by Professor Vavilov on "Breeding as a Science". The second volume is devoted to more specific problems in the breeding of grains, legumes, and grasses. The third volume deals with the breeding of potatoes, vegetables, tobacco, citrus and other fruits, industrial plants, such as flax, hemp, cotton, and rubber, etc.

Each chapter is followed by an extensive bibliography, mostly Russian references. (J. W. P.)



Doctor Percy Edgar Brown

DOCTOR PERCY EDGAR BROWN

1885–1937

IN the passing of Dr. Brown, Iowa State College has lost one of her ablest and most highly respected staff members; agriculture has lost a leading educator, research worker, and administrator; and all who worked with or knew him have lost a very dear and loyal friend and helpful adviser.

He was a teacher of outstanding ability because of his magnetic personality, friendliness and ability to inspire his students to master the subject under consideration.

He was eminently successful as a research worker in the fields of Soil Bacteriology, Soil Fertility and Soil Survey. He was recognized as an authority in this country and abroad, and few men of his age have published as many scientific articles, bulletins, etc., as the appended partial bibliography indicates.

As a successful administrator Dr. Brown had few equals. His work was planned with a definite goal in mind; he delegated responsibility and demanded good results.

He lived an exemplary life and by virtue of his fine personality, high character and ability he commanded the highest respect and loyalty of all who worked with him.

Dr. Brown was born on a farm at Woodbridge, New Jersey, October 9, 1885, and died suddenly of coronary thrombosis at his home on the morning of July 8, 1937, as he was preparing to leave for his office.

He was graduated from Woodbridge High School in 1902 and received his B. S. degree from Rutgers College, New Brunswick, New Jersey, in 1906.

From 1906 to 1910 he served as assistant soil chemist and bacteriologist at the New Jersey Agricultural Experiment Station in close association with Dr. J. G. Lipman and received his A. M. degree from Rutgers in 1909. On many occasions Dr. Brown stated that no man had influenced his life or given greater inspiration to his life work than Dr. Lipman.

In 1910 he was assistant professor of soil bacteriology at Iowa State College, and following the conferring of the Ph.D. degree by Rutgers College in 1912 he was promoted to the rank of associate professor and to a full professorship in 1914. During the year 1931 Dr. Brown served as acting head of the Department of Agronomy and was made head in 1932 which position he held at the time of his death.

For a number of years Dr. Brown was secretary of Section O (Agriculture) of the American Association for the Advancement of Science and a Fellow of that association. He was consulting Editor of "Soil Science", Fellow of the Iowa Academy of Science, and member of the American Chemical Society.

At a meeting of the American Society of Agronomy at Massachusetts State College in 1920, Dr. Brown was nominated for the office of Secretary-Treasurer by Dr. Stevenson. He was elected and held

the office from then to the time of his death, except for the year 1932 when he served as President. He was also among the first 12 Fellows elected to the Society in 1925. The great contribution which Dr. Brown made to that organization over a long period of years has prompted J. D. Luckett, Editor of the JOURNAL of American Society of Agronomy, to say, "I feel that the American Society of Agronomy and all that it stands for today is one of the many splendid monuments that Dr. Brown has left to his enduring memory."

In 1926 he was President of the American Soil Survey Association; in 1913, Councilor for the Society of American Bacteriologists; and in 1918, expert on the National Research Council. He was also a member of the American Organizing Committee for the First International Congress of Soil Science and one of the 12 delegates appointed to attend that convention in Washington.

After the organization of the Soil Science Society of America in 1935 he served as Secretary-Treasurer of the American Society of Agronomy and Treasurer of the Soil Science Society of America.

It was only natural that a man of his training and ability should become actively affiliated with many honor societies, including Sigma Xi, Phi Kappa Phi, Alpha Zeta, Gamma Sigma Delta, Phi Lambda Upsilon, and Phi Beta Kappa. He was also a member of the Delta Upsilon social fraternity.

For many years Dr. Brown was most active in Masonic work in the State of Iowa. In keeping with the high standard of excellency which he maintained in every undertaking, he served every high office attainable in the several orders to which he belonged, diligently and faithfully, receiving the K. C. C. H. degree in 1921.

Not only did he have time to carry on the many activities as listed above, but he also took part in community affairs as well. He, his mother, Mrs. Jeanette E. (Walker) Brown, and sister, Edna, who survive him were faithful members of the Presbyterian Church. Dr. Brown was a Rotarian, member of the Ames Chamber of Commerce, Ames Golf and Country Club, the Iowa Authors Club, the Mono Clan Fraternity, and Sons of the American Revolution. In the Iowa State College he served on many important committees.

In the quality of his work, in his friendly cooperative spirit, and in all his associations with his many colleagues and friends, he demonstrated that he was a true friend and a big man in every sense of the word.

"The words he spoke, the works he did and the life he lived were the agencies through which he manifested himself", to his students and his colleagues. Many of the men who carried on their graduate work under his inspiring leadership have achieved distinction and greatly enlarged the scope of Dr. Brown's influence as a teacher. Just as every trustworthy mariner knows the port toward which he is heading, so Dr. Brown at all times without faltering, guided his department toward the goals which he and his staff had agreed were most worthy of their united efforts. To the office of Secretary-Treasurer of the American Society of Agronomy he brought all of the efficiency, vigor and untiring effort that marked all of his administrative activities, without reckoning the time and energy expended as long as

the interests of the Society were served and the organization continued to prosper.

By all who were privileged to know him and particularly those who had the opportunity of being intimately associated with him, the memory of Dr. Brown will be forever cherished. As the less worthwhile things in life fade out and disappear, the accomplishments of his life will stand out with increasing clarity and boldness, as worthy work well done, a life of service well lived, a life that inspired others and therefore lives on through the years.

May we who live, honor our beloved friend by greater endeavor and achievements ever holding to his standards of service and high ideals.—B. J. FIRKINS.

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MINUTES OF THE THIRTIETH ANNUAL MEETING OF THE SOCIETY

THE thirtieth annual meeting of the Society was held at the Stevens Hotel in Chicago on November 30 to December 3. There were 713 registered at the meetings.

The general meeting of the Society was held Thursday morning, December 2, President Frederick D. Richey presiding. "The Relation of the National Agricultural Conservation Program to Agronomic Betterment" was discussed by M. A. McCall, Bureau of Plant Industry, and "Integrating Research and Extension" was the subject of a paper by R. D. Lewis, Ohio State University.

The annual dinner was held on Thursday evening, with the address of the President, "Why Plant Research?", as the feature of the occasion.

The Soil Science Society of America held meetings on Tuesday, Wednesday, Thursday afternoon, and Friday, with programs on soil physics, soil chemistry, soil microbiology, soil fertility, soil morphology, and soil technology. The Committee on Fertilizers of the Society, with its subcommittees, met Tuesday afternoon in a business session. The Crops Section had programs arranged for Wednesday, Thursday afternoon, and all day Friday.

The Auditing Committee appointed by President Richey consisted of Professor B. J. Firkins and Dr. G. Wiebe. The nominating committee consisted of President Richey, *Chairman*, O. S. Aamodt of the Crops Section, and Richard Bradfield of the Soils Section.

COMMITTEE REPORTS

VARIETAL STANDARDIZATION AND REGISTRATION

During the year, no new undertakings were initiated by the Committee on Varietal Standardization and Registration. One variety of barley, Regal, two varieties of wheat, Canawa, and Apex, and three varieties of sorghum, Finney milo, Club, and Early kalo, were registered. The wheat and barley varieties are described on pages 1031 to 1033 of this number of the JOURNAL.

H. B. BROWN	H. K. HAYES	T. R. STANTON
J. A. CLARK	W. J. MORSE	G. H. STRINGFIELD
E. F. GAINES	J. H. PARKER	M. A. MCCALL, *Chairman*

BIBLIOGRAPHY OF FIELD EXPERIMENTS

The committee has compiled a bibliography of 72 titles of the more important contributions on the methodology and interpretation of results of field plat experiments, either reported since or not included in the revised bibliography published in the JOURNAL (Vol. 25:811–828, 1933; and the additions in Vol. 27: 1013–1018, 1935; Vol. 28:1028–1031, 1936).

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Respectfully submitted,

F. R. IMMER H. M. TYSDAL
J. T. MCCLURE H. M. STEECE, *Chairman*

PASTURE RESEARCH

Pasture research in America is expanding rapidly and, in general and insofar as physical and biological factors permit, it is advancing along the same broad lines as pasture research in Europe, although America is still a generation behind Europe in some aspects of pasture improvement. Moreover, America probably has farther to go to reach the same goal as Europe because of greater diversity of climate, greater expanse of territory and difficulty in overcoming the effects of mal-practices in land use.

Pasture research activities in Europe are of three major types: (1) Building and testing improved strains of pasture plants; (2) use of fertilizers; and (3) grazing practices. The interrelationship of all three types of research is recognized and all are considered, in a general way, in connection with tests designed to determine the place and economy of pastures in cropping systems suited to different types of arable land.

Strain building and testing involves close cooperation among plant breeders, agronomists, animal husbandmen, seed growers and others concerned with the production and maintenance of adequate seed supplies and their use in pasture improvement. Strains are tested under a wide range of physical conditions, alone and in mixtures, and under grazing. These tests seek superiority in herbage values, regeneration, resistance to disease, persistency under pasture conditions, palatability, and nutritive value. Once the superiority of a strain is established, it is multiplied as rapidly as possible for distribution, in accordance with a plan to insure maintenance of supply. In the meantime, demand for superior strains has been stimulated by demonstration plantings and pasture tests.

Fertilizer tests, coupled with grazing tests, aim to determine methods of maintaining the desired balance of species in the herbage as well as maximum carrying capacity. Here again close cooperation is maintained among all agencies interested in pasture improvement.

In advancing pasture improvement in this country, America may profit by European experiences as they relate (1) to pasture research and (2) to the integration of research with extension activities.

In research, America could well afford to promote closer coördination (a) among various units within each state agricultural experiment station and within the federal Department of Agriculture; (b) among all agencies within the respective pasture regions. Efforts to effect closer coordination are already in progress in some states and in certain regions, notably the Northeastern Region in connection with the U. S. Regional Pasture Research Laboratory. Less formal, but possibly equally effective coordination is being promoted among states and the federal Department in other regions. But it is apparent that much good could be accomplished by further efforts along this line.

There is reason to believe also that research agencies would be justified in extending their pasture improvement projects to determine the place and economy

of pastures in cropping systems on good farm land as well as upon existing pastures which, for the most part, are found only on land not well suited to the production of other crops.

In a general way pasture research problems may be classified as follows:

(1) Those pertaining to the collection, selection and breeding of plants that:
  (a) Are palatable to the kind of livestock concerned
  (b) Will yield well and persist under grazing and other prevailing conditions
  (c) Give satisfactory production of livestock and livestock products
  (d) Have a favorable effect upon the health and reproduction of the livestock
  (e) Can be readily propagated and controlled

(2) Those pertaining to the use of soil amendments—lime, fertilizer, etc., and involving:
  (a) The type of soil
  (b) The kind of amendment to use
  (c) The method of application
  (d) The time of application, and how each and all of these factors affect the time, amount and quality of production

(3) Those pertaining to the effect of different times, methods and types of grazing, mowing, etc., upon—
  (a) The stand of herbage and relative abundance of various species
  (b) The quality of the herbage
  (c) The yield of herbage
  (d) The production of livestock and livestock products
  (e) The health of the livestock
  (f) The economic returns.

(4) Those pertaining to the development of a farm pasture program which will combine the desirable plants, treatments and practices into a practicable system that will provide an abundant and uniform supply of high quality pasture at all times from early spring to late fall. It is conceivable that the pasture season might be materially lengthened.

In order to promote better correlation and coordination in pasture research work it is suggested: (1) that more frequent state and regional conferences be held, including all agencies concerned with pasture research problems; (2) that coordinators or coordinating committees be created in the various states and regions; and (3) that a representative of the federal Department be designated to give general aid and guidance in an advisory way only to the pasture workers of the various states.

It is evident, however, that pasture improvement in America awaits not only the results of research but the development of a greater grass consciousness among farmers themselves. This calls for clearer appreciation of the value of good pastures and the factors which are conducive to the improvement of pastures, as the use of improved strains, the intelligent use of fertilizers, and the adoption of better grazing practices. To this end it is highly important that research and extension activities be closely integrated and that this integration provide for the encouragement of extension activities which will fortify and help to attain the broader objectives of research.

In order to develop a pasture consciousness and greater pasture activity among farmers, it is suggested that encouragement be given to such as the following:

(1) State and County pasture tours, field meetings, schools and conferences

(2) The inclusion of pasture improvement in dairy, beef cattle and sheep 4-H projects.
(3) The development of pasture herbage gardens.
(4) The appointment of a representative of the extension service and the experiment station in each state, probably on a fifty-fifty basis, whose business it would be to encourage new extension pasture projects and collect data from farmers under various soil and climatic conditions and which would have research as well as extension value.

The exact manner in which your Joint Committee on Pasture Research could most effectively function in helping to promote pasture improvement in America is still problematical. However, if the American Society of Agronomy is to maintain a liason with other societies interested in pasture improvement and thereby serve as a guide to research and extension work in this field, it would appear that this Committee has a place in the organization which it should continue actively to occupy. As means of strengthening its position and of increasing its effectiveness, your Committee offers the following recommendations:

(1) That the name of the Committee be changed to Joint Committee on Pasture Improvement.
(2) That the membership of the Committee be increased, possibly from 9 to 12.
(3) That the membership of the Committee be approximately one-half from extension workers, and that in the selection of members all three major phases of Agronomy—soils, plant genetics and plant physiology—be represented.
(4) That the Committee adopt each year certain definite objectives upon which to base its annual report to the Society. An immediate objective might well be to report on the comparative nutrient value of various crops, including pasture crops, to show the relative costs of digestible nutrients.

Among other suggested objectives may be named the following:

(a) Possibilities for regional coordination of pasture improvement activities.
(b) Examples of coordinated pasture improvement programs within State Stations and other agricultural research agencies.
(c) New developments in permanent pasture work.
(d) Supplemental pastures.
(e) New crop possibilities for permanent pastures.
(f) Progress in pasture plant improvement.
(g) Progress in pasture management.
(h) The place of pastures in the Soil Conservation Program.

In closing, your Committee takes occasion to record with profound regret, the death on February 22 of one of its most interested and constructive members, H. N. Vinall.

Respectfully submitted,

O. S. Aamodt — H. D. Hughes
A. E. Aldous — George Stewart
B. A. Brown — Paul Tabor
D. R. Dodd — P. V. Cardon, *Chairman*

STUDENT SECTIONS

During the past year the Student Section of the American Society of Agronomy has approved the petitions of agronomy students of the following institutions: Pennsylvania State College, Colorado State College, and North Dakota State College.

The essay contest was stimulated this year as the result of added funds for awards. The prizes offered were: The first three winners to receive expense money up to a total of $50 each to permit them to attend the International Grain and Hay Show and the 1937 meeting of the American Society of Agronomy in Chicago. In addition each man received an appropriate medal and a year's subscription to the JOURNAL of the American Society of Agronomy. The winners of 4th, 5th, 6th, 7th, and 8th places received cash prizes of $25, $20, $15, $10, and $5, respectively.

Thirty-five papers were entered in the essay contest. Essays were judged by the members of the committee assisted by Karl Manke and Weldon Shepherd of Nebraska, H. E. Myers of Kansas State College, and A. C. Arny, University of Minnesota. The titles of the first eight papers and their authors follow:

1. The Rôle of Boron in Plant Growth, John W. Bengtson, University of Nebraska.
2. The Rôle of Boron in Plant Growth, Hugh G. Myers, Kansas State College.
3. The Rôle of Iron in Plant Growth, Arnold Petersen, University of Nebraska.
4. Pasture Improvement in the United States, Olman Hee, University of Minnesota.
5. Soil Water in Plant Growth, Gilbert L. Terman, Kansas State College.
6. Pasture Improvement in the United States, Patrick H. Smith, Alabama Polytechnic Institute.
7. The Importance of Soil Conservation, Eugene Hamilton, Iowa State College.
8. Pasture Improvement in the United States, Robert F. Lichty, Iowa State College.

The committee has noted a considerable advance in the quality of the essays as most of the papers submitted showed evidence of painstakingly thorough preparation.

The committee expresses grateful appreciation to Mr. Clarence Henry and the Chicago Board of Trade for financial assistance in connection with the contest. Mr. Henry and his group have granted $200 in cash to the Society, financed the purchase of appropriate medals, and paid the printing costs for the essay booklets distributed at the Society's banquet.

The committee recommends that the Society continue to sponsor the essay contest during the coming year.

During the past year certificates of affiliation with the American Society of Agronomy were issued to groups of agronomy students in 14 institutions.

Respectfully submitted,

G. H. DUNGAN J. B. PETERSON
A. L. FROLIK J. W. ZAHNLEY
H. K. WILSON, *Chairman*

FERTILIZERS

Subcommittee on Fertilizer Application.—The Subcommittee on Fertilizer Application has continued to function as one of the constituent subcommittees of the National Joint Committee on Fertilizer Application. The fertilizer placement studies of this committee now have covered a nine year period, the volume of the work increasing each year. In 1937 there were conducted 119 experiments at 62 locations in 28 states on 22 crops. The latter included: corn, cotton, tobacco, sugar beets, potatoes, bluegrass pasture, wheat, alfalfa, soybeans, lima, snap, string, wax and white beans, cabbage, cauliflower, celery, collards, kale, lettuce, onions, peanuts, peas, spinach, tomatoes and sweet potatoes.

Some studies of fertilizer equipment have been made including a study in South Carolina of commercial equipment for applying fertilizer to cotton; studies in Montana and South Dakota relative to grain drill fertilizer equipment; studies in Ohio of fertilizer depositors combined with vegetable seeders; and a study in Montana of liquid phosphoric acid application in irrigation water.

Supplementing previously published surveys of fertilizer application practices with field and vegetable crops, a similar survey dealing with fruit and nut trees has been completed and a report will soon be issued.

R. M. SALTER, *Chairman*

Subcommittee on Soil Testing.—The American Chemical Society meeting at Rochester, New York, included a program of papers dealing with soil testing, arranged by the Fertilizer Section of the A. C. S. This attracted the attendance of most of the membership of the Subcommittee, and a meeting was held at that time. This was followed by a considerable amount of correspondence between the membership of the committee. As decided at Rochester, a survey of the present use of "quick" chemical tests by the agricultural colleges and experiment stations in the various states has been under way. This has met with excellent response, only five institutions having failed to report to date. A detailed analysis of the data obtained in this survey will be published in the JOURNAL in an early issue.

A similar survey will be made of commercial soil testing. Much of this work is now being done through the agencies of fertilizer organizations, processing establishments, etc., as a service for their clients or producers. In numerous instances "quick" chemical tests are used by commercial agricultural advisers. In general, the state institutions have exerted no control over this work, but have been helpful in giving instructions as to technique and interpretations of results.

The Subcommittee is working out the details of a definite plan for furnishing representative samples of a considerable number of soils for correlative testing by various methods now in use or that may be developed. It is expected that these will become available during the spring of 1938.

From information received as a result of the soil testing survey, it is apparent that the relative merits of the various methods of soil testing under local conditions have not been fully investigated. The Subcommittee recommends that experiment stations do as much work as possible along this line and cooperate with us by furnishing reports of their results.

It is recommended that the Subcommittee on Soil Testing be continued.

M. P. MORGAN, *Chairman*

Subcommittee on Fertilizer Grades.—It appears unfruitful at this time to attempt the adoption of a uniform system for selection of fertilizer grades for use throughout all states.

The matter of reduction of the number of grades offered for sale in any given state or region seems of more pressing importance at present than the selection of grades according to a uniform system.

A reduction in number of grades offered for sale may be accomplished on a regional basis more effectively than on the basis of the entire fertilizer-using area.

It is recommended that the committee continue its work on the grade problem, focusing its attention largely on the matter of reduction of number of grades offered for sale in given regions. It is proposed that the committee conduct its work in the regions established through the medium of subcommittees, members of the present committee serving as chairmen of the subcommittees.

C. E. MILLAR, *Chairman*

Subcommittee on Symptoms of Malnutrition in Plants.—A special meeting of the subcommittee was held in Washington February 23, 1937, at which plans were considered for the publication of a book dealing with malnutrition symptoms of important crop plants, written in semi-technical language and well illustrated with colored plates. Certain chapter authors were designated to prepare subject matter for all sections with provision for due credit for anyone furnishing material. During the year members of the subcommittee have busied themselves in the collection of suitable material illustrating in natural color symptoms of malnutrition in plants. A review of the literature has been prepared for publication. One publication has already appeared and others are in preparation or in process of publication dealing with symptoms of malnutrition in certain crop plants.

J. E. MCMURTREY, *Chairman*

Subcommittee on Fertilizer Reaction.—The Chairman reported briefly last year on the results of three years of active work by the Committee, listing a number of important accomplishments and stating that several years of field experimentation would be required before some of the field tests on the efficiency of the neutral fertilizers in relation to soils and crops, could yield satisfactory conclusions. It was recommended that the Subcommittee be continued so that it could resume active functions whenever further evidence justified further attention.

While the Committee as such has not been active this past year, a number of important papers on the subject have been published by members and others. Attention is also called to the fact that a number of States have placed requirements in their fertilizer regulations or laws concerning acid-forming or non-acid-forming fertilizers. These include Alabama, Florida, South Carolina, North Carolina and Virginia.

It is recommended that the Subcommittee be continued for the purpose of assisting experimenters and reporting from time to time on the progress of the experimental field tests under way at various points.

OSWALD SCHREINER, *Acting Chairman*

CORN HYBRIDS

The Committee on Corn Hybrids was instructed to cooperate with a similar committee to be appointed by the International Crop Improvement Association in the consideration of interstate problems and policies by corn breeders, extension agronomists, seed improvement associations, and seed producers. Although the two committees have not had an opportunity for joint action on these problems, during the year the members of both committees have discussed the various problems concerned.

It is the opinion of the Committee that the greatest progress will be made along these lines through the perfection of an informal organization of the State and Federal corn workers which would provide opportunity for the free and open discussion of problems and policies as they arise. It is understood that such an organization is to be perfected at these meetings.

Respectfully submitted,

T. A. Kiesselbach H. D. Hughes
G. H. Stringfield Merle T. Jenkins, *Chairman*

EXTENSION

Your Committee on Extension feels that there is continued need for the closest association of the Extension Agronomists with the latest developments and thinking of the research worker in agronomy. We also feel that the Extension Agronomists have a contribution to make by bringing to the research workers of this Society the practices of good farmers and the results obtained in applying the findings of research to the problems of the farmer.

We recognize the responsibility of the Extension Agronomist in bringing agronomic problems to the attention of research workers, and possibly in helping to plan certain types of research work. We recognize the responsibility of the Extension Agronomists in assisting the research worker in analyzing their work and putting it in proper form to carry to the farmer.

In order to be prepared to assist in this work we feel that the Extension Agronomists will get the broadest possible view of the whole field of research by attending the meetings of the American Society of Agronomy and we pledge ourselves to bring this to the attention of all Extension Agronomists during the coming year.

Finally, we suggest that in planning programs, that insofar as possible, they be developed with the thought of attracting and using all agronomists, and your Committee offers to furnish the program committees with suggestions in so far as extension agronomists are concerned.

Respectfully submitted,

E. R. Jackman J. S. Owens
Earl Jones P. H. Stewart
J. C. Lowery O. S. Fisher, *Chairman*

RESOLUTIONS

Following the procedure established with the appointment of a standing Committee on Resolutions, your committee has continued as one of its functions, to take note of the death of agronomists who have long been active in their lines of work. It is with sorrow and a feeling of great loss, not only to the Society, but to their respective families, that we must record the deaths of Percy Edgar Brown, Iowa State College, Ames, Iowa; Harry Nelson Vinall, U. S. Dept. of Agriculture, Washington, D. C.; John Milton Westgate, Hawaii Agricultural Experiment Station, Honolulu, T. H.; Carl Petty Blackwell, Oklahoma A. & M. College, Stillwater, Okla.; Paul Emerson, Soil Conservation Service, Rapid City, S. D.; and S. D. Wicks, Syracuse, N. Y.

A statement regarding the life and work of each of these men is appended hereto as a part of this report.

Respectfully submitted,

R. J. Garber R. I. Throckmorton
M. F. Miller J. D. Luckett, *ex officio*
F. D. Keim, *Chairman*

Harry Nelson Vinall

HARRY Nelson Vinall, 57, died suddenly February 22 at his home in Washington, D. C., as the result of a heart attack. He was Senior Agronomist in the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, with which he had been connected since 1906. Born on a farm near Nevada, Story County, Iowa, the son of George W. and Delina Neal Vinall, he was graduated in 1903 from the Kansas State Agricultural College, and, in 1912, received the degree of Master of Science from Cornell University. He is survived by his widow, Mary Agnes Austin Vinall.

Mr. Vinall was long active as a member of the American Society of Agronomy, a frequent contributor to the Journal and for years chairman of the Joint-Committee on Pasture Research. He was also a member of the American Association for the Advancement of Science, the American Genetic Association, Botanical Society of Washington, Association of Southern Agricultural Workers, Sigma Xi, and Phi Kappa Phi.

In the early years of Mr. Vinall's service in the U. S. Dept. of Agriculture he interested himself in various forage crops, especially in field peas and millets to which subjects he made important contributions. Later he centered his attention on the sorghums and was responsible for the development and introduction of many new varieties. Both administratively and personally he took a deep interest in problems of genetics, especially as worked out with sorghums. His work with the sorghums culminated in a comprehensive study of the identification, history, and distribution of common sorghums.

From 1926 on he was mainly interested in the development of pasture research and took active part in working for the increased interest in this subject which has been so marked in the last decade. He had under his administrative supervision a number of field stations where pasture research is conducted; he outlined the problems and methods to be followed and kept in constant touch with the field workers.

His contributions to the Journal of the American Society of Agronomy appeared in Volumes 5, 8, 13, 20, 21, 24, 25, 27, and 28. He also contributed to the *Journal of Heredity*, *The Book of Rural Life*, and to various farm papers. He was author of the article on "Grass and Grassland" in the *Encyclopedia Britannica*. His bulletins, circulars, and leaflets published by the U. S. Dept. of Agriculture are too numerous to list at this time.—P. V. Cardon.

John Milton Westgate

DIRECTOR of the Hawaii Agricultural Experiment Station in Honolulu for twenty years, professor of agriculture at the University of Hawaii, and consultant in tropical agriculture at the Hawaii Experiment Station from 1935 to the time of his death, John Milton Westgate died in Honolulu September 25 at the age of 59 years.

Surviving are two sons, Philip John Westgate, a graduate student at the University of Wisconsin, and Mark Wheeler Westgate, who is completing work for his Ph.D. at the University of Hawaii; a brother, Harold Westgate of Manhattan, Kansas; and a sister, Mrs. Helen Lewis of Arkansas.

Professor Westgate was born February 17, 1878, in Kingston, Ulster County, New York. He graduated from the Kansas State College of Agriculture with the B. S. degree in 1897 and in 1899 obtained his M. S. degree at the same institution. From 1901–03 he attended the University of Chicago for advanced study.

Westgate's teaching career began in his early student years when he acted as assistant botanist from 1897–1901 at the Kansas State College of Agriculture. He became assistant agrostologist, U. S. Dept. of Agriculture, in 1903, remaining in charge of soil-binding investigations until 1905, when he was placed in charge of alfalfa and clover investigations, retaining the position until 1914, the last three years as agronomist devoting his time primarily to clover investigations.

In 1915 he was appointed Agronomist in charge of the Hawaii Experiment Station, which title was changed to Director in 1924. He joined the faculty of the University of Hawaii in 1935 as professor of tropical agriculture, a position for which he was exceptionally well fitted through many years of agricultural research and recent extensive travel and study in tropical countries under the auspices of the University and the U. S. Dept. of Agriculture.

Westgate was the author of numerous important bulletins and papers on agronomical subjects, one of the most outstanding of which was U. S. Dept. of Agriculture Farmers' Bulletin No. 339, entitled "Alfalfa" and published in the early nineties, which still remains a classic treatise on leguminous crops, a field in which he was an acknowledged leader.

Westgate was a Fellow and Life Member of the American Association for the Advancement of Science, a Life Member of the American Genetics Association and the Botanical Society of America, and a Charter Member of the Amerian Society of Agronomy and of the Hawaiian Academy of Science, also a member of Phi Kappa Phi and Pi Gamma Mu.

His relationship with his associates was tinged with idealism to an unusual degree. He had a breadth of sympathy for all classes and races, with a special interest in the racial problems of Hawaii, particularly in the philosophy of the Oriental. He became a student of the Chinese language. In his position as Director and as Professor of Tropical Agriculture he came in touch with many young Americans of Oriental parentage and his contribution to the Americanization of these young citizens was outstanding.

Westgate's colleagues in Hawaii and many friends throughout the scientific world have lost a sincere and capable fellow worker and a friend who cannot be replaced; he will be greatly missed. Their deep sympathy and condolence are extended to his family and relatives in their bereavement.—F. G. KRAUSS, J. C. RIPPERTON, and O. C. MAGISTAD.

CARL PETTY BLACKWELL

CARL Petty Blackwell was born in Lampasas County, Texas, on November 5, 1886. His parents moved to Greer County when he was nine years old.

In 1906 he entered Oklahoma Agricultural and Mechanical College and graduated from that institution in 1911. He received a Master of Science degree from the University of Wisconsin on June 16, 1915. During the summer of 1915 he enrolled for graduate work at the University of California. Additional graduate work was completed at Cornell University. He was a member of Alpha Zeta, Phi Kappa Phi, Phi Delta Kappa, Alpha Gamma Rho, Rotary Club, and was an active leader in the Presbyterian church. In 1933–1934 he was president of the Association of Southern Agricultural Workers.

His professional career began in the rural schools in southwestern Oklahoma. From 1911 to 1914 he was high school principal at Stillwater and Okmulgee. In the fall of 1914 he became an instructor in Agronomy at the University of Texas. In the fall of 1917 he went to Cornell University to continue his graduate work. In

the fall of 1918 he became Professor and Head of the Agronomy Department at Clemson College, South Carolina, where he remained until 1925. He was associated with the Soil Improvement Division of the National Fertilizer Association from 1925 to 1928. In the fall of 1928 he became Dean of the School of Agriculture and Director of the Oklahoma Agricultural Experiment Station which position he held until his death which occurred March 4, 1937.

He was married to Lillian Stiernberg at Port Lavaca, Texas, on June 8, 1916. His wife and two children, Carl Petty, Jr., and Lucille, survive him.—H. J. Harper.

Paul Emerson

Dr. Paul Emerson, Senior Scientist of the Soil Conservation Service, died in a lonely canyon near Rapid City, South Dakota, on July 16th, apparently after a futile effort to save himself from the fatal effects of a rattlesnake bite. He had gone out to collect soil samples for a paper he planned to present at the 1937 meetings of the Soil Science Society of America. When he failed to appear at his office three days later, a party of soil conservation officials began searching and found his body slumped against his auto with a tourniquet around his left leg to prevent poison from the bite reaching his heart.

Dr. Emerson was born in Wilmington, Delaware, July 6, 1887. He received his B. S. degree at the University of Delaware in 1914, and his M. S. and Ph. D. degrees at Iowa State College in 1915 and 1917, respectively.

Dr. Emerson was Soil Bacteriologist at the Maryland Experiment Station, 1917–1918; acting Bacteriologist, University of Idaho and Idaho Experiment Station, 1918–1919; Assistant Professor of Soils and Assistant Chief of Soil Chemistry and Bacteriology, Iowa State College, 1919–1922, and Associate Professor of Soils, Iowa State College, 1922–1932. In 1935 he became Senior Scientist for the Soil Conservation Service at Huron, S. D. and was later transferred to Rapid City.

Dr. Emerson served well as a teacher, author and scientist. His tireless efforts in helping students will make them long remember him. His keen interest in soil science resulted in the publication of two books, "Soil Characteristics" and "Principles of Soil Technology", widely used in colleges and universities. He was also the author of numerous bulletins and scientific papers.

As senior Soil Scientist for the Conservation Service he found the work he loved best. He died in the field of duty, truly a martyr to the cause of Soil Science. He was a member of the American Association for the Advancement of Science, former member of the American Society of Agronomy, member of the American Soil Survey Association, the American Chemical Society and the International Society of Soil Science. He was also a member of the Executive Committee of the American Association of University Professors for several years. He belonged to Sigma Xi, Phi Kappa Phi, Gamma Sigma Delta, Phi Lambda Upsilon and Alpha Zeta, honor societies.

He served on the Board of Deacons of the Episcopal Church in Ames. Dr. Emerson is survived by his widow and two sons, Paul Jr., and Reynolds, all of Ames, Iowa.—L. W. Erdman.

OFFICERS' REPORTS

REPORT OF THE EDITOR

The past year has been comparatively uneventful so far as the affairs of the Journal are concerned. The 1937 volume promises to be almost a duplicate of the 1936 volume as the following figures indicate:

There have been 143 papers received up to the time of writing this report; there were 141 at this time last year. Of this number 109 will be published as compared with 113 in 1936; 17 papers have been returned to the authors for one reason or another; 11 were returned last year; and 17 are either awaiting publication or are under review, which checks exactly with the figure for last year.

We shall publish 12 notes in the current volume, as compared with 13 in 1936; and 26 book reviews as compared with 16 last year. But in number of pages and general make-up, the two volumes will be much alike and will not differ greatly in cost.

Over against this we have a very substantial increase in membership in the Society, which means an increase in the support of the JOURNAL, and also a much better showing in advertising income, with the result that the Treasurer's report will indicate a larger cash balance on hand than for many years—if it does not actually set a record in that respect.

This balance has added significance over the mere fact that we close the year in good financial standing. From the time that your Editor first took over the business management of the JOURNAL in 1924 up to the present, the JOURNAL year and the Society year have never coincided, with the result that, while the books might show a favorable balance, there were never sufficient funds to round out the current volume of the JOURNAL without drawing on the dues for the next year to complete the volume then coming to a close.

If this is a bit involved, let me illustrate: This year we have already paid for 12 numbers of the JOURNAL and still have ample funds, *without tapping our 1938 receipts*, to pay for the November and December numbers of the 1937 volume. In other words, we have at last taken up the slack and will start even with receipts and JOURNAL volume in 1938.

Beyond the satisfaction of balancing the budget, there is no immediate advantage to be realized from this consumation of a long-cherished hope on the part of the officers of the Society, but it augurs well for the future, we believe, in that, assuming that we can hold our own, it will permit a modest expansion in the size of the JOURNAL, if and when such an expansion seems desirable, or should allow us gradually to build up a reserve for possible lean years ahead.

The experience of the past year answers very well, we believe, the misgivings expressed by some as to the possible effects upon the JOURNAL of the recent reorganization of the Society, and particularly of the inauguration of the PROCEEDINGS of the Soil Science Society of America. We never shared in these misgivings, because the PROCEEDINGS of the Soil Science Society constitute, just as the name implies, the proceedings of meetings of the different soils groups, and the JOURNAL has long since ceased to be dependent upon the programs of the annual meetings for material. This past year has been no exception; in fact we published fewer papers from the 1936 annual meeting than usual and yet easily maintained a normal publication schedule.

The PROCEEDINGS and the JOURNAL each has its own well-defined field of operation and as the years go by they should supplement each other more and more effectively—as we believe they have done this past year.

One other interesting observation of the year that might be worthy of note is the increasing number of papers that are being submitted to the JOURNAL from abroad. Perhaps this is not to be wondered at when we consider that very nearly 25% of our mailing list is now of foreign origin. These papers are not yet of sufficient number to make any great impression on the character of the JOURNAL, but in the normal course of events they and the ones that will inevitably follow

upon their publication, will tend to give the JOURNAL a slightly international tone, which personally we believe to be a trend in the right direction in increasing the prestige of the JOURNAL and of the Society, both at home and abroad.

I have left until the end mention of the great loss that all of us sustained last summer, and that we have felt so keenly ever since. The word about Doctor Brown's passing reached me in a small town in Indiana, and the first reaction was a feeling of utter inability to continue without him. Lacking first-hand knowledge of the close interworkings of the Secretary's office and the management of the JOURNAL, one cannot fully appreciate what this break meant. And coupled with that was a close tie of personal friendship that had grown with the years, despite the fact that in all that time our paths never crossed except at the annual meetings of the Society. These all-too-few occasions and the pleasure of having known and worked with him will always remain among my most cherished memories.

In concluding this report, I want to congratulate the Society on its good fortune in having had available and willing to take over the arduous duties of the office of Secretary and Treasurer one who not only had had experience in discharging the duties of the office, but also one who had immediate access to the Society's records.

Dr. Smith has had the difficult task not only of carrying forward the affairs of the American Society of Agronomy, including arrangements for this meeting, but also the responsibility of the financial affairs of the Soil Science Society. He has done a splendid job and we are deeply indebted to him for invaluable aid rendered on innumerable occasions during the past few months. We also wish to take this occasion to express our thanks to Dr. T. L. Lyon, Chairman of the Editorial Advisory Board, and to that large and hard-working, but of necessity, anonymous group of reviewers who have performed their task so cheerfully and so well.

Respectfully submitted,
J. D. LUCKETT, *Editor*

REPORT OF THE SECRETARY

May I take this occasion to pay tribute to the man who, for a number of years, was my teacher, superior officer, and friend, and who was for so many years our distinguished and beloved Secretary, Dr. P. E. Brown. During the 13 years I was associated with Dr. Brown it was my privilege to act for him on several occasions. In this report, I continue that service. Had it not been for his careful attention to details and efficient organization of the office, the completion of the work of the year would have been difficult, indeed. I would also like to express my appreciation to the officers of the Society for their fine spirit of cooperation and the help they have given me. I am especially grateful to Dr. J. B. Peterson of Iowa State College for the assistance he has given in mailing the Journals from Ames. With this help, I have been able to keep the work of the Secretary's office moving, I hope, without too much delay.

We are able to announce again this year that the membership in the Society is the largest in the history of the organization. The changes in membership from last year are shown in the following figures:

Membership, last report		1,166
New members, 1937	196	
Reinstated members	86	
Total increase	282	

Dropped for non-payment of dues	203	
Resigned	27	
Died	5	
Total decrease	235	
Net increase		47
Membership, October 31, 1937		1,213

The subscription list has been increased as the following figures will indicate:

Subscriptions, last report		603
New subscriptions, 1937	180	
Subscriptions dropped	134	
Net increase	46	46
Subscriptions, October 31, 1937		649

The memberships and subscriptions by states and countries are as follows:

	Members	Subscriptions
Alabama	20	1
Arizona	14	2
Arkansas	9	4
California	44	9
Colorado	17	2
Connecticut	15	4
Delaware	3	1
District of Col.	90	5
Florida	23	3
Georgia	17	4
Idaho	9	1
Illinois	49	9
Indiana	28	3
Iowa	57	4
Kansas	49	2
Kentucky	17	3
Louisiana	14	3
Maine	8	1
Maryland	18	5
Massachusetts	12	3
Michigan	24	6
Minnesota	34	3
Mississippi	16	7
Missouri	29	4
Montana	9	5
Nebraksa	30	2
Nevada	3	1
New Hampshire	3	1
New Jersey	16	4
New Mexico	10	2
New York	50	17
North Carolina	25	3
North Dakota	13	1
Ohio	57	3
Oklahoma	14	5
Oregon	20	3
Pennsylvania	33	9
Rhode Island	6	1
South Carolina	15	3
South Dakota	11	1
Tennessee	7	3
Texas	59	9
Utah	13	6
Vermont	4	1
Virginia	23	1
Washington	22	2
West Virginia	12	1
Wisconsin	35	1
Wyoming	6	1
Alaska	0	1
Canada	23	34
Cuba	4	1
Hawaii	12	12
Philippine Islands	1	2
Puerto Rico	3	3
Africa	5	23
Argentine	8	12
Australia	1	22
Austria	1	0
Brazil	0	5
British Guiana	0	1
British W. Indies	1	1
Ceylon	0	3
Chile	0	1
China	0	51
Czecho-Slovakia	0	1
Denmark	2	1
Dutch E. Indies	0	4
Egypt	1	2
England	1	12
Estonia	0	1
Fed. Malay States	0	5
Fiji	0	1
Finland	0	4
France	0	12
Germany	3	10
Greece	3	5
Haiti	1	0
Holland	0	3
Honduras	1	0
Hungary	1	0

	Members	Subscriptions		Members	Subscriptions
India........	7	20	Peru	0	4
Indochina ...	0	1	Poland.	1	2
Ireland......	0	2	Portugal.....	0	3
Italy........	0	8	Roumania....	1	1
Japan.......	4	98	Scotland	1	3
Jugoslavia.. .	0	2	Siam........	2	2
Mauritius....	0	1	Spain	1	0
Mesopotamia.	1	1	Sweden......	0	4
Mexico......	0	5	Switzerland...	1	1
Morocco.....	0	1	Turkey......	1	1
New Zealand.	0	5	Uruguay.....	1	1
Norway......	0	1	U. S. S. R ...	4	70
Nova Scotia..	1	0	Wales.......	0	3
Palestine.....	1	0			
Panama......	1	0			
Persia.......	1	1	Totals...	1,213	649

We are very greatly indebted to the special representatives of the Society in the various states and bureaus of the U. S. Dept. of Agriculture for bringing in new members during the year. Special mention for the largest numbers of new members sent in should be made of Dr. R. V. Allison of the University of Florida and of Professor Emil Truog of the University of Wisconsin. It will be remembered that Dr. Allison sent in the largest numbers of new members last year. We want to thank all these men and many others who have given us help during the year. May I ask your continued cooperation and loyal support as it is through the membership that we are able to pay our bills and publish a high class journal.

In this connection I would direct your attention again to the membership changes in 1936–1937. We dropped more members for non-payment of dues than new members taken in, and except for the relatively large number of members reinstated we would have had a net decrease in membership this year. We have carried a large number of members whose dues are in arrears and I am hopeful that a large percentage of these men will reinstate their membership because we need their support.

We have paid for 12 issues of the JOURNAL and all other bills of the Society. Our cash balance in the treasury is larger than it has been in a number of years. Advanced dues are coming in but many of these do not show in our balance as the books of the Society were closed October 31.

The summer meeting of the Corn Belt Section of the Society was held at the Michigan State College June 22 to 24. The meeting of the Northeastern Section of the Society was held June 28 to 30 in Massachusetts and New Hampshire. The Western Branch held its twenty-first meeting at the Montana State College July 19 to 21 and the meeting of the Southern Section of the Society was held in Tennessee August 16 to 22 under the auspices of the University of Tennessee.

Respectfully submitted,

F. B. SMITH, *Secretary*

REPORT OF THE TREASURER

I beg to submit herewith the report of the Treasurer for the year November 1, 1936, to October 31, 1937, as follows:

Receipts

Advertising income..	$ 988.97
Reprints sold..	1,429.89
Journals sold..	288.79

Subscriptions, 1937	2,174.98
Subscriptions, 1936	44.90
Subscriptions, 1937, new	878.35
Subscriptions, 1938	102.20
Dues, 1937	4,281.75
Dues, 1936	445.50
Dues, 1937, new	1,001.67
Dues, 1938	205.89
Subscriptions, Soil Science Society, 1937	130.00
Dues, Soil Science Society, 1937	2,304.64
Subscriptions, Soil Science Society, 1938	0.00
Dues, Soil Science Society, 1938	13.50
Membership only, Soil Science Society, 1937	56.50
Membership only, Soil Science Society, 1938	2.50
Payment on trust certificates	163.30
Soil Survey Association fund	520.00
Sale of Soil Survey Association bulletins	92 35
Fees, I. S. S. S., 1937	500.00
Fees, I. S. S. S., 1938	35.00
Total receipts	$15,660.68
Balance in cash, Nov. 1, 1936	773.08
Total income	$16,433.76

Disbursements

Printing the JOURNAL, cuts, etc.	8,072.30
Salary Business Manager and Editor	748.25
Postage (Business Manager and Secretary)	261.85
Printing, miscellaneous	130.64
Express on Journals	47.84
Mailing Clerk	449 50
Refunds, checks returned, etc	149.79
Miscellaneous, expense annual meeting, etc.	336.44
Printing Proceedings, etc., Soil Science Society	2,591.29
Fees transmitted to Dr. D. J. Hissink (I. S. S. S.)	528.25
Total disbursements	$13,316.15
Balance on hand, Nov. 1, 1937	$ 3,117.61
Balance in trust certificates	410.88
Total balance in account	$ 3,528.49
Balance in cash in hand	3,117.61

Respectfully submitted,
F. B. SMITH, *Treasurer*

REPORT OF THE AUDITING COMMITTEE

The Auditing Committee appointed by President F. E. Richey, has examined the ledgers, vouchers, and records of the Treasurer and find all accounts correct in every detail.

Respectfully submitted,
G. A. WIEBE
B. J. FIRKINS, *Chairman*

REPORT OF THE ASSISTANT TREASURER

Dr. A. G. McCall submitted the following report of the Assistant Treasurer which was referred to an auditing committee comprised of Dr. J. J. Skinner, *Chairman*, and Dr. Alexander.

Record of Distribution of Proceedings of First International Congress o. Soil Science (1927) November 10, 1936 to November 17, 1937

On hand in storage with the Rumford Press, Concord, New Hampshire, as of November 10, 1936	804 sets
Sold during the period November 10, 1936 to November 17, 1937	6 sets
Balance on hand in storage	798 sets

Distribution as follows:

2 sets @ $11.50
2 sets @ 10.50
1 set @ 6.50
1 set @ 5.50

Collections as follows:

2 sets	@ $11.50	=	$23.00
2 sets	@ 10.50	=	21.00
2 sets	@ 6.50	=	13.00
1 set	@ 5.50	=	5.50
			$62.50

NOTE: Collections include payment for some orders shipped prior to the period covered by this report and for some orders shipped during this period payment has not yet been received.

American Society of Agronomy in Account with Executive Committee of the First International Congress of Soil Science

November 11, 1936 to November 17, 1937

Receipts

Sale of Proceedings of First International Congress of Soil Science (1927)	$62.50	
Interest on Savings Account in Prince Georges Bank and Trust Co., Hyattsville, Md	58.01	
Membership dues from American members of the International Society of Soil Science	420.40	
*Amount erroneously included in deposit of $361.70 in Prince Georges Bank & Trust Co., Hyattsville, Md. Jan. 18, 1937, when it should have been deposited in the account maintained for American Section dues, in McLachlen Banking Corporation, Wn., D. C. Voucher Check No. 481 dated Jan. 18, 1937 in favor of A. G. McCall, Secy-Treas. American Section, withdrew this amount from the Prince Georges Bank & Trust Co., and it was then deposited by the payee in the proper account in the McLachlen Banking Corporation, thus correcting the mistake. This item therefore appears on both receipts and expenditures of this financial statement. (See below starred item)	57.90	
Balance on hand Prince Georges Bank and Trust Co., Hyattsville, Md., as of November 10, 1936	$2,687.02	
		$3,285.83

Expenditures

Postage (stamps and envelopes for office correspondence in connection with membership records, proceedings orders, etc.)	15.00
The Rumford Press, Concord, New Hampshire, for handling and shipping sets of Proceedings of the First International Congress of Soil Science	6.19

Premium on bond for Dr. A. G. McCall, Ass't. Treasurer, American Society of Agronomy		5.00	
Transmittal to Dr. D. J. Hissink, General Secretary, of the Internat'l Society of Soil Science, Groningen, Holland, dues collected from American members		420.40	
*Voucher check No. 481 dated Jan. 18, 1937, issued to make transfer of the amount erroneously deposited in Prince Georges Bank & Trust Co., to the proper account in McLachlen Banking Corporation. (See above starred item for explanation)		57.90	
Deduction by Prince Georges Bank & Trust Co., Aug., 24, 1937 for exchange on check drawn on Royal Bank of Canada, Province of Quebec, deposited for Proceedings		15	
Check No. 476 dated Nov. 9, 1936	$6.80		
Check No. 477 dated No. 7, 1936	6.32		
Both were outstanding on report for year ending Nov. 10, 1936; deducted by bank in year ending Nov. 17, 1937, but not deducted by us this year because entered in expenditures by us for last year		13.12	
Balance on hand Prince Georges Bank & Trust Co., Hyattsville, Md., as of November 17, 1937. Savings account (which includes $1,000 contribution to Endowment Fund)	$2,634.71		
Checking account	133.36		
		2,768.07	
			$3,285.83

(See attached letter of Nov. 17, 1937 signed by the Treasurer of the bank verifying this)

International Society of Soil Science, American Section, record of collection of dues for 1935-1936 1937

Dues collected for 1935 (65 members @ 50 cents—some members paid for 2 years)		$34.50
Dues collected for 1936 (113 members @ 50 cents)		$56.50
Dues collected for 1937		$77.40
(96 members @ 80 cents)	$76.80	
1 new member initiation	.30	
1 member made partial payment, balance to follow	.30	
Total		$168.40
Check No. 1 dated May 13, 1937 in favor of J. E. Gieseking, Agricultural Experiment Station, Urbana, Illinois, being contribution toward expense of preparing film of the 1935 Third International Congress of Soil Science		28.46
Amount on deposit with McLachlen Banking Corporation, Washington, D. C.		$139.94

(See attached letter of November 16, 1937 signed by the Assistant Treasurer of the Bank, verifying the balance)

November 29, 1937.

Submitted by

A. G. McCall,

Assistant Treasurer, American Society of Agronomy and Secretary-Treasurer American Section, International Society of Soil Science

FELLOWS

Vice-President Emil Truog announced the Fellows Elect and presented the diplomas. Those elected were Dr. O. S. Aamodt, Dr. W. A. Albrecht, Dr. F. E. Bear, Dr. H. O. Buckman, Dr. G. W. Conrey, Professor H. D. Hughes, Dr. F. D. Keim, Dr. R. D. Lewis, Professor J. D. Luckett, and Dr. H. L. Westover.

AMENDMENT APPROVED

The admendment to Article VI of the constitution adding the two immediate past Presidents of the Society to the Executive Committee was approved.

REPORT OF THE NOMINATING COMMITTEE

Dr. Richard Bradfield presented the report of the Nominating Committee and upon motion the Secretary was instructed to cast a unanimous ballot for the following: Ralph J. Garber, Vice-President; Emil Truog and H. K. Hayes, representatives of the Society on the Council of the American Association for the Advancement of Science; and P. V. Cardon and R. M. Salter, executive representative and alternate, respectively, on the National Research Council. Dr. Emil Truog automatically succeeded to the Presidency and A. M. O'Neal automatically succeeded to the Presidency of the Soil Science Society. Dr. Ide P. Trotter was elected to the Chairmanship of the Crops Section.

Meeting adjourned.

F. B. SMITH, *Secretary*

AGRONOMIC AFFAIRS

OFFICERS OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1938

THE following persons constitute the officers of the Society for 1938:

President: EMIL TRUOG, University of Wisconsin
Vice-President: R. J. GARBER, Bureau of Plant Industry
President Soil Science Society of America: A. M. O'NEAL, Bureau of Plant Industry, U. S. Dept. of Agriculture
Chairman of Crops Section: IDE P. TROTTER, Texas Agr. Exp. Station
Secretary-Treasurer: F. B. SMITH, University of Florida
Editor: J. D. LUCKETT, New York State Experiment Station
Members of the Executive Committee: F. D. RICHEY, Bureau of Plant Industry.; R. M. SALTER, Ohio Agr. Exp. Station

OFFICERS OF THE SOIL SCIENCE SOCIETY OF AMERICA FOR 1938

President: A. M. O'NEAL, Bureau of Plant Industry, U. S. Dept. of Agriculture
Secretary: W. A. ALBRECHT, University of Missouri
Treasurer: F. B. SMITH, University of Florida

Section I—Soil Physics

Chairman: L. A. RICHARDS, Iowa State College
Secretary: G. B. BODMAN, University of California

Section II—Soil Chemistry

Chairman: E. E. DeTurk, University of Illinois
Secretary: J. W. Tidmore, Alabama Polytechnic Institute

Section III—Soil Microbiology

Chairman: N. R. Smith, Bureau of Plant Industry, U. S. Dept. of Agriculture
Secretary: A. W. Hofer, New York State Experiment Station

Section IV—Soil Fertility

Chairman: H. J. Harper, Oklahoma Agricultural Experiment Station
Secretary: J. J. Skinner, Bureau of Plant Industry, U. S. Dept. of Agriculture

Section V—Soil Morphology

Chairman: W. E. Hearn, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture
Secretary: S. S. Obenshein, Virginia Agricultural Experiment Station

Section VI—Soil Technology

Chairman: E. A. Norton, Soil Conservation Service
Secretary: W. L. Powers, Oregon Agricultural Experiment Station

MINUTES OF THE CROPS SECTION BUSINESS MEETING CHICAGO, ILL., DECEMBER 2, 1937

THE report of the Committee on Nomenclature of corn hybrids was made by Dr. M. T. Jenkins. It was recommended that since the American Society of Agronomy now has a standing committee on corn hybrids there was no further need for the special committee on Nomenclature of Corn Hybrids, and a motion to that effect was unanimously approved.

The report of the Executive Committee of the Crops Section on the reorganization of the Section was presented by the Chairman of the Section, as follows:

REPORT ON THE REORGANIZATION OF THE CROP SECTION PROGRAMS OF THE AMERICAN SOCIETY OF AGRONOMY BY THE 1937 EXECUTIVE COMMITTEE

Previous to preparing this report a redigest was made of the questionnaire received from the members of the Society in the survey conducted last fall. It is clearly evident that the majority of the members favored reorganization into some sort of sectional groups at their annual meeting. The purpose of these groups is to unify the interests of the various workers. It is an attempt to unite workers rather than to cause their separation by forming distinct subdivisions in the Society.

Of those favoring reorganization a great majority favored development along the lines of the various sciences, while the others seemed to favor development along the line of the major crops together with symposia, or round tables, on special topics of current interest. The questionnaires also indicated that the mem-

bers were practically unanimous in their interest in joint meetings between Crops and Soils Sections to take care of naturally overlapping subject matter of interest to different groups.

The 1936 Executive Committee made the following recommendation in their report last year:

> "It is proposed that there be 3 subsections of the Crops Section: Subsection No. 1 shall embrace the fields of breeding, genetics and cytology; Subsection No. 2, the fields of physiology (including nutrition), morphology, and taxonomy; and Subsection No. 3, all other phases of crops not covered in the preceding subsections."

The 1936 report was accepted at the time of the Washington meetings and referred to the 1937 Executive Committee for reconsideration in providing a plan for reorganization at the next year's meeting. Your committee attempted to follow a compromise on the various suggestions that have been made and experiment in the organization of the Crops Section Program for the 1937 Annual Meetings. Previous years' experience indicate rather definitely that there is a serious limitation on the organization of a good program by merely issuing a general call for papers. Experience seems to indicate that the best meetings are those in which papers are solicited or informal arrangements made for discussion of a given topic. Not only are outstanding men obtained by this method but the subject is more likely to be properly developed in an interesting fashion. Your last year's chairman, Howard B. Sprague, had the following to say on this point:

> "Our experience last fall indicates that we cannot rely entirely upon volunteer papers in arranging a fully satisfactory program. Possibly some combination of the invitation type of program and that consisting of papers sent in voluntarily, would be preferable to having one type or the other. Looking back on the experience last fall, it seems to me that we might have been successful in developing programs in physiology, genetics, and Southern field crops, as was ordinarily planned, if we had made a definite effort to solicit papers from given individuals. Our attempts to bring in papers on these subjects by merely issuing a general invitation, were not successful in spite of the fact that considerable investigation is being conducted along these lines."

Early in the present year inquiries were made by your Executive of members and the Society and others interested as to what subjects they thought would be of vital interest to members of the Society as a topic for discussion at their annual meeting. Several suggestions were received which appeared to have possibilities for the development of either formal programs with papers or round table discussions. This procedure gradually resolved itself into a program which may be summarized as follows:

1. Section or sections on genetics, cytology and breeding.
2. Section or sections on physiology, morphology, and ecology.
3. Sections for symposia, or round tables, on special topics of current interest, such as
   a. Some aspects of vegetative methods of erosion control.
   b. Nitrogen fixation by leguminous plants.
   c. Weather-crop relations.
   d. Induced polyploidy in relation to plant breeding.
   e. Miscellaneous papers.
   f. Etc.

The general call for papers published in the September issue of the JOURNAL had a very poor response. This is in agreement with the experience of your previ-

ous chairman and others. Wherever possible the miscellaneous papers received were grouped with the special sections or arranged for in a section for miscellaneous papers.

The organization of sectional meetings on special topics of current interest was done by soliciting the assistance from leaders in each of the special fields of activity. These leaders were requested to organize the details of the program and arrange for the papers or discussion. A considerable portion of the success in organizing the present program must be credited to the activity and fine cooperation received from these men who were delegated to act as chairmen for the various sectional meetings.

Organizations interested in field crops such as the International Crop Improvement Association and the Seed Council of North America were conferred with relative to the coordination of their annual meetings with the various sectional meetings of the Society.

No thought has been entertained relative to the organization of special groups along definite lines similar to the Soils Groups and their affiliation with the Soil Science Society of America. The Crops group is in no way suggesting a modified relationship with the parental organization, The American Society of Agronomy, or its JOURNAL, for the publication of its papers.

With this explanation as a basis for our plan of reorganization of the Crops Section Program we wish to respectfully resubmit the following plan which is modified slightly from that submitted last year, for your consideration:

A PROPOSED PLAN FOR REORGANIZATION OF THE CROPS SECTION PROGRAMS AMERICAN SOCIETY OF AGRONOMY

It is proposed that there be three major groups in the Crops Section with programs as follows:

I. Section or sections on genetics, cytology, and breeding.
II. Section or sections on physiology, morphology and ecology.
III. Section or sections on miscellaneous topics of current interest dealing with special crops or agronomic problems.

It is proposed that there be an Executive Committee consisting of 3 members elected annually, one of whom shall serve as chairman of the Crops Section, and shall be responsible for the activities of Subsection No. 3. The remaining 2 members of the Executive Committee shall act as secretaries of Subsections 1 and 2, respectively, and shall arrange suitable sectional programs for the annual meetings, as desired by the membership of the Society. The chairman shall arrange for such programs or discussions on specific crops embracing various phases of plant sciences, on specific regional problems, on statistics and plot technique, on teaching and extension, as may be deemed desirable, and shall also provide for joint programs with soils groups when mutually desired.

It is also proposed that Crops Section programs at annual meetings shall not exceed 2½ days (plus ½ day for general meeting of the Society), with specialized programs occurring in the earlier periods of the meeting and the more general programs during the latter periods. The time and place for the business meeting of the Crops Section will be arranged for by the Executive Committee.

IDE P. TROTTER
L. E. KIRK
O. S. AAMODT, *Chairman*

The above plan for reorganization of the Crops Section was unanimously approved by the members present.

The report of the Nominating Committee of the Crops Section, comprised of H. B. Sprague, *Chairman*, M. T. Jenkins, and R. D. Lewis, for the 1938 Executive Committee was as follows: Ide P. Trotter, *Chairman*, F. D. Keim, and R. J. Garber. There were no further nominations from the floor and the above recommendations were unanimously approved.

1938 SUMMER MEETING OF CORN BELT SECTION

THE summer meeting of the Corn Belt Section of the Society will be held at the College of Agriculture, University of Missouri, Columbia, Mo., June 21, 22, and 23, 1938. The occasion will give opportunity to observe the fiftieth anniversary of the founding of the Missouri Agricultural Experiment Station and of the establishment of Sanborn Field by the late Dr. J. W. Sanborn. This is one of the older experiment fields in the United States.

While details of the program have not yet been worked out, plans include sessions at Columbia and field trips for observation of the soils of the state and visits to outlying experiment fields.

CHANGES IN SIZE LIMITS FOR SILT AND CLAY

THE Bureau of Chemistry and Soils announces a change in size limits reported for silt and clay.

After January 1, 1938, reports of the Bureau will indicate as clay that fraction of soil particles less than 2 microns in diameter, and as silt that fraction between 2 and 50 microns. In addition, the fraction below 5 microns will be determined as in the past, so that the data obtained under the new scheme can be related to that already published. The five coarser fractions between 50 microns and 2 mm will be reported as in the past.

The Bureau has made many other changes in the mechanical analysis procedure which makes it possible to report results also by the International system. An extra sieving has been added at 0.2 millimeter and a pipetting at 20 microns. Reports will be made according to both systems, thus making it possible to compare data with those reported in the literature under either the former American or the International system.

It is hoped that these changes will make the data from mechanical analysis more useful. The change to 2 microns for the upper limit for clay has the effect of bringing about a better correlation between field textural classification and classification from the data of mechanical analysis. The reduction in size limits tends to reduce the percentage of clay, thus offsetting in part the higher percentage gotten by modern dispersion methods.

This action has been submitted to the state agricultural experiment stations and has received general approval.

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